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SUBSURFACE CORRELATION BY MEANS OF HEAVY MINERALS[1]

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ABSTRACT

This paper describes an attempt to make practical use of heavy-mineral zones as a means of determining structure in a part of the San Joaquin Valley where other means were not available. It presents a part of the data, along with a discussion of their bearing on some of the general principles involved. The conclusion is reached that the method is likely to be of considerable use if it is applied with due regard to certain limitations.

GEOLOGY OF THE LAZARD AREA

This paper presents the scientific results of an attempt to use heavy-mineral zones to correlate the strata penetrated in a series of core holes. The area selected for a test of this method is known as the Lazard estate and is located a few miles west of Lost Hills, in the San Joaquin Valley, California (Fig. 1). It is deeply covered by alluvial material, which was penetrated by more than twenty-five holes scattered over a few square miles of land. Physiographically it is part of Antelope Plain, a great alluvial fan built by Bitterwater Creek between the Temblor Range and the slough that drains into Tulare Lake. The surface of the plain is interrupted here and there by lines of low hills, several of which, like Lost Hills, are known to mark the sites of nearly buried anticlines. That part of the fan under discussion here lies almost directly east of the north end of the Temblor Range and the south end of the Diablo Range.

The character of the rocks underlying the Lazard tract must be inferred, to a great extent, either from exposures in the hills west of Antelope Plain or from data

[1] Read before the Association, Pacific section, at Los Angeles, October 29, 1926. Manuscript received by the editor, January 10, 1927. For permission to publish some of the results of this investigation the writers are under obligations to R. E. Collom, chief geologist of the Marland Oil Company of California. In drilling the holes and securing suitable samples many difficult engineering problems were solved by R. M. Barnes, with the assistance of H. H. Wright. The writers had little to do with this phase of the problem, and make no attempt to discuss it.

secured from deep holes. From these two sources it was known at the beginning of the investigation that some hundreds of feet of alluvial material would first be penetrated. Beneath the alluvium are lake beds of clay and sand several hundred, or a few thousand, feet thick. They grade downward into marine Pliocene (Etchegoin) strata, likewise a few thousand feet thick. These are underlain by marine Miocene siliceous shale, of which more than 9,000 feet are exposed in the Temblor Range. Of these several formations the heavy mineral investigation was concerned with only the two youngest. The alluvium constituted an overburden which had to be drilled through in order to secure samples from beds in which it was hoped to find usable heavy-mineral zones which had been involved in any possible folding.

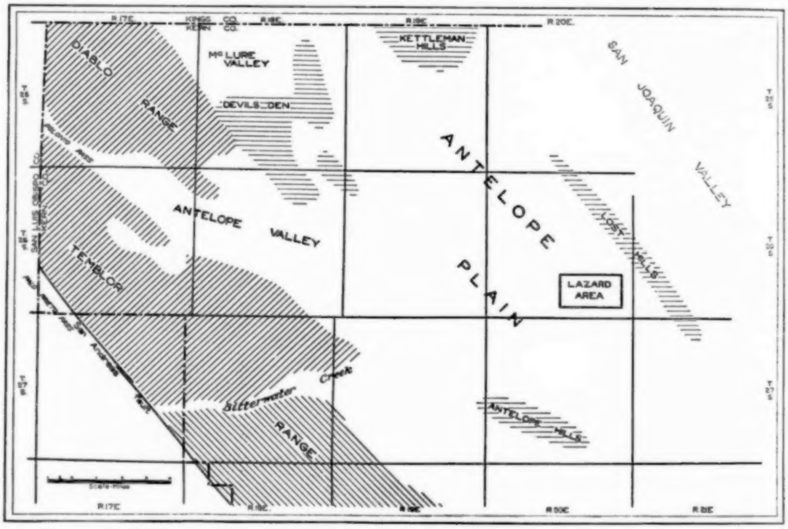

FIG. 1.—Sketch map of part of northeastern Kern County. The direction of lines in the south end of the Temblor Range is without special significance.

Its thickness proved to be about 500 feet. In other areas it might be much less, or absent; and in still others, too great to make core-drilling for samples practicable.

Just what older rocks underlie the Lazard land is uncertain and not relevant to the present discussion. The basement rocks of the adjacent mountains, however, are of great interest, since they are known ultimately to have furnished most of the detritus for the more recent lake beds, as well as for the alluvium. In the Diablo Range, and in the northernmost part of the Temblor Range, the oldest rocks are Franciscan schists, cherts, and igneous rocks, characterized, as a whole, by large numbers of peculiar minerals, glaucophane being a typical one. Farther south, on the other hand, Franciscan rocks do not occur, their place being taken by granite or rocks derived from granite, with the usual pyrogenetic minerals.

A single phase of geologic history concerns this paper—the conditions that existed during some of the later stages of the ancestral Tulare Lake. In late Pliocene time this body of water is known to have spread widely over the western part of the southern San Joaquin Valley, and perhaps still farther west. Into it occasional floods from the rising Diablo and Temblor ranges swept masses of gravel, sand, and mud, which were distributed by waves and currents over the shallow lake bottom. At any given time the drainage systems of the land and the direction of the dominant lake currents might have brought chiefly Diablo schist fragments and minerals to a given small area, such as the Lazard tract and the immediately surrounding region. Changes must have been frequent, however, and need not have been great to cause this material to be carried elsewhere, while Temblor granitic material began to accumulate here. The probability of such geographic changes was pointed out, in fact, in a paper[1] published before the core-drilling investigation had started. At that time, however, several important points, such as the thickness and mineralogical distinctness of the zones, and the sharpness of their boundaries, were still doubtful.

DRILLING, CORING, AND SAMPLING

A portable rotary outfit was used for drilling test holes. In the first holes cores were taken every 15 feet and at every change in lithology, as guessed by the driller. Ditch and bit samples were saved from intermediate horizons in the mistaken belief that they might prove useful in supplementing the data gained from core samples. After the thickness of the alluvium and the character of zones in the underlying beds had been determined, and the usefulness of ditch and bit samples evaluated, a different drilling program was adopted by the engineers in charge. They "fish-tailed" nearly through the alluvium, then cored continuously until a sufficient number of heavy-mineral zones had been penetrated. This procedure was highly satisfactory and was followed in all later drilling. Each day the engineer in charge in the field sent to the laboratory in San Francisco a small sample by special delivery. From an examination of these samples the petrographer was able to give advice regarding depth to abandon, location of new holes, and similar problems.

For detailed study composite samples were carefully made in the field and sent to the laboratory. Each core was freed from drilling mud and cut into sections $1\frac{1}{2}$ feet long. Each section was split, half of it kept in the field, and the other half quartered so as to make a single sample. Smaller core sections would, of course, have given slightly more accurate results, but would have increased the total number of samples to be handled, and therefore the cost in time and money.

TREATMENT OF SAMPLES IN THE LABORATORY

After examination with a hand lens, part of each sample was placed in a beaker and boiled an hour in dilute hydrochloric acid. This process destroyed the car-

[1] R. D. Reed, "Rôle of Heavy Minerals," *Econ. Geol.*, 1924, p. 744.

bonates and cleansed the grains from iron oxide and other coatings. The material was next placed in a large beaker, agitated with water, allowed to settle, and the mud carefully decanted. This operation was repeated until the sample was free from material so fine as to interfere with further treatment. The remaining clean sand and silt were then washed into a crucible and dried on a hotplate.

The dry material from each sample was next treated with bromoform, according to the method proposed by Cayeux[1] and adopted by Reed[2] for an earlier investigation. This method has been adversely criticized by Woodford[3] and by Ross,[4] both of whom greatly prefer to use a separatory funnel. For some purposes there can be little question that the funnel method is preferable, and it has been occasionally used, as a matter of fact, by the present writers for years. Prolonged experience leads to the belief, however, that it is too time-consuming to be used in commercial work. Cayeux's method, on the other hand, if skilfully used, is rapid and easy, and gives sufficiently accurate results.

The heavy-mineral concentrate was washed into a filter paper with a stream of benzol from a wash-bottle, dried, and filed for petrographic examination.

PETROGRAPHIC EXAMINATION OF HEAVY MINERAL CONCENTRATES

A Leitz petrographic microscope, SY No. 2, with rotating nicols, was used with daylight illumination in determining mineral grains. Temporary mounts were made, using a set of immersion oils of known indices of refraction. Larsen's determinative tables proved most helpful, but were supplemented by frequent reference to all the standard textbooks.

To obtain the percentages of different detrital minerals is a tiresome task, and several methods were employed: (1) counting the grains along a line as the mechanical stage propels the slide across the field, (2) counting the grains of each species in several fields with or without the use of a grid ocular, and (3) mere estimates of percentages by inspection. The last method, after checking and rechecking, eventually became fairly accurate, but was never used in determining zonal limits.

THE HEAVY MINERALS

The core samples yielded a considerable number of heavy minerals, which are listed in Table I. In some zones, as had been anticipated, the great majority of the minerals were of metamorphic character and must have been derived from Franciscan schists; in others, pyrogenetic minerals strongly predominated. Some detrital grains, much worn, probably came from older sedimentary rocks. Most of the grains were extremely fresh and angular, however, suggesting a crystalline source

[1] L. Cayeux, *Introduction a l'Étude Petrographique des Roches Sédimentaires* (Paris, 1916), p. 66.

[2] R. D. Reed, "Methods for Heavy Mineral Investigation," *Econ. Geol.*, 1924, p. 326.

[3] A. O. Woodford, Discussion, *Econ. Geol.*, 1925, p. 103.

[4] Clarence S. Ross, "Methods of Preparation of Sedimentary Materials for Study," *Econ. Geol.*, 1926, p. 454.

and slight abrasion before deposition. The plentiful feldspars, as was learned by occasional examinations of the light fraction of a sample, were likewise fresh and angular.

TABLE I

Actinolite	Epidote	Spodumene
Anatase	Garnet	Spinel
Andalusite	Glaucophane	Staurolite
Apatite	Hornblende	Titanite
Augite	Hypersthene	Topaz
Barite	Kyanite	Tourmaline
Basaltic hornblende	Lawsonite	Tremolite
Benitoite	Limonite	Uvarovite
Brookite	Magnetite	Vesuvianite
Corundum	Piedmontite	Zircon
Crossite	Pyrite	Zoisite
Dumortierite	Rutile	Unknown mineral
Diopside	Sillimanite	

The unknown mineral mentioned last in Table I merits a word of description. It belongs to the orthorhombic crystal system. It is characterized by intense pleochroism, changing from colorless to a deep ultramarine blue when the vibration direction of the lower nicol is parallel to the axial plane of the mineral. The refractive indices have not been accurately determined, but two are less than, and one greater than, 1.74. The mineral has a negative sign, high dispersion, and an optic axial angle of about 10°. It has three good cleavage planes. It could not be found in the determinative tables.

Barite, extremely plentiful in some of the cores from the alluvium, but occasionally found also in the lower beds, is particularly interesting. It occurs as a rule in the form of six-sided plates, but also as small euhedral crystals, and as rosettes. Its form indicates development within the sediments rather than a detrital origin. The barium is presumed to come from the decomposition of feldspars or micas, the sulphates from the groundwaters of this arid region. The widespread occurrence of barite in British shales and slates has been noted by Hutchings.[1] Casual inspection of a few scattered samples suggests that it is plentiful also in many California clays and shales.

Most of the magnetite grains noted are clearly of detrital origin; but a few, in the form of dendrites, are secondary.

The frequent occurrence of pyrite, especially in some of the clay beds, is noteworthy. Some concentrates showed as much as 99 per cent pyrite, all of it apparently of secondary origin. The grains were of many different shapes: some were clearly pseudomorphs after, or coatings of, hornblende and other minerals; others had replaced rootlets, twigs, fish remains, re-worked diatoms, and other materials. Some grains looked like spherical concretions.

[1] W. Hutchings, "The Origin of Some Slates," *Geol. Mag.*, 1890, p. 266.

Concerning the other minerals, a great number of interesting observations were made and many of them recorded. None of these bore particularly on the correlation problem, however, and further discussion of the subject is therefore omitted.

THE HEAVY-MINERAL ZONES

Several holes penetrated all of the zones shown in Table II. To save expense, however, many of the later holes did not go much below the main amphibole zone, No. 4 of the table. Except for the disappearance of the pyrite and gastropod zones, no hole failed to find an expected zone at the appropriate depth; and the changes from hole to hole in thickness of zones and in mineral composition were gratifyingly slight.

TABLE II

HEAVY-MINERAL ZONE

1. First granitic zone. Undivided alluvium, about 500 feet
2. Augite zone. Uppermost lake beds, 10–20 feet
3. Second granitic zone. 22–27 feet
4. Amphibole zone. Main zone for correlation. About 87 feet
5. Pyrite zone. Subzone of the last. 0–20 feet thick

5-A. Gastropod zone. 0–10 feet, also in Zone 4, below pyrite

6. Third granitic zone. 15–25 feet
7. Amphibole-garnet zone. 15–20 feet
8. Fourth granitic zone. Deepest holes stopped in top of this zone

A typical assemblage from one of the so-called "granitic" zones would be about as follows: titanite, 25 per cent; zircon, 20 per cent; epidote, 25 per cent; magnetite, 20 per cent; hornblende, biotite, garnet, basaltic hornblende, and rutile make up most of the remaining 10 per cent. Traces of rare minerals such as brookite, benitoite, corundum, anatase, dumortierite, spinel, and piedmontite, are occasionally found; also random grains of such metamorphic minerals as andalusite and glaucophane, but never in amounts large enough to cause confusion.

The augite zone is peculiar in that it carries a mixed assemblage of granitic and metamorphic minerals, with augite predominant. In addition, there are noticeable amounts of garnet, common hornblende, glaucophane, tourmaline, zircon, epidote, titanite, and magnetite. Many uncommon minerals, such as hypersthene, staurolite, kyanite, spinel, and andalusite, are nearly always present, though always in small amounts. The average number of different minerals for all samples from this zone is more than sixteen.

The amphibole zone is so definite and clear-cut that no mineralogical skill is required to recognize it. Minerals of the amphibole group constitute 50 to 95 per cent of the heavy concentrate. Of the amphiboles present, 90 per cent are common hornblende, the green variety predominating over the brown. Other amphiboles present are actinolite, basaltic hornblende, tremolite, glaucophane, and rarely a

few grains of soda-rich varieties. The non-amphibole minerals include epidote, pyrite, zircon, and small amounts of nearly all the others listed in the table. The same minerals, with the addition of 50-99 per cent pyrite, make up the pyrite zone, which has been stated to be a subzone of the amphibole zone.

The gastropods, which were discovered during the preparation of the cores, are similar to those commonly found in outcrops of Tulare sediments. The fossil zone was not persistent, but was picked up in a few holes, and constituted a valued orthodox check on the new type of correlation that was being worked out at the time. An amphibole assemblage of heavy minerals, with secondary pyrite, accompanied the gastropods.

The amphibole-garnet zone differs from the amphibole zone chiefly in the presence of 15–25 per cent of garnet, and in a slight dominance of brown hornblende over green. Some pyrite is present.

Each of the heavy-mineral zones included a number of lithologic members.

DETERMINATION OF ZONAL LIMITS

Since the cores were usually cut into sections 1½ feet long, the zonal limits could not always be determined as closely as might otherwise have been done. At times, however, shorter lengths of core were made into composite samples, and occasionally a special sample, consisting of a segment cut from a core, contained the zonal boundary within itself. Some figures regarding different samples will give a general idea of the sharpness of boundaries of the amphibole zone.

TABLE III

AMPHIBOLE ZONES

	SPECIAL SAMPLES	
Well A	Core at 556.4	2% hornblende
	Core at 557.0	10% hornblende
	Core at 557.5	40% hornblende
Well I	Core at 558.2	2% hornblende
	Core at 558.5	30% hornblende
	COMPOSITE SAMPLES	
Well O	Core from 534.3–535.3	10% hornblende
	Core from 535.3–536.3	12% hornblende
	Core from 536.3–537.7	56% hornblende
	Core from 538.5–540.0	65% hornblende
Well X	Core from 531.5–533.0	Rare hornblende
	Core from 533.0–534.0	2% hornblende
	Core from 534.0–536.2	35% hornblende
	Core from 536.2–536.8	65% hornblende

In a few cases loss of a core at a critical depth made the determination of a zonal boundary uncertain by as much as 5 feet. In spite of such accidents, the boundary of the amphibole zone—our structural datum—had an average margin

of uncertainty of less than 2 feet. Some other zones appeared to have less sharply defined boundaries. With sufficiently detailed study, however, any of them could probably have been made the basis for a satisfactory structural study.

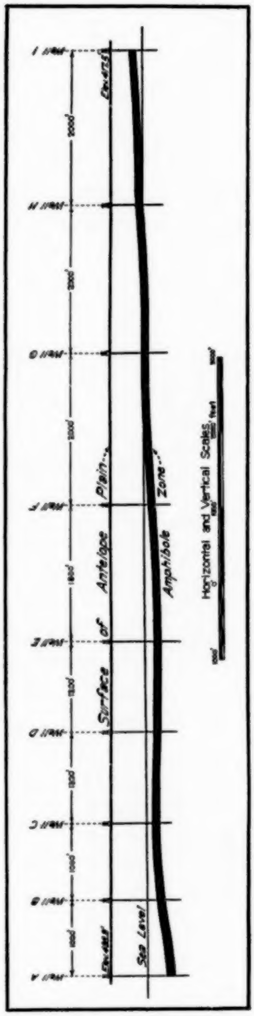

FIG. 2.—Section showing the amphibole zone along an east-west line across the Lazard tract

CAN ZONES BE FOUND ELSEWHERE?

On the question whether or not zones like those described are likely to be found generally, this investigation does not throw as much light as could be wished. As already suggested, conditions in the Lost Hills district may be unusually favorable for heavy-mineral correlation. On the other hand, it may be pointed out: first, that a similar alternation of definite zones had previously been shown to exist throughout the Miocene and Pliocene formations of the Coalinga district, and in a 5,000-foot section of Fernando beds from Ventura;[1] second, that in any basin which has several petrographically varied distributive provinces, like the Los Angeles Basin, the chances of finding distinctive zones would seem especially favorable; and finally, that a reliable correlation could have been made with zones much less distinct than those actually found on the Lazard tract. The writers are fairly confident, at any rate, that recognizable zones can be found by a sufficiently intensive study of properly chosen samples from almost any lacustrine or marine series of clastic strata.

HOW FAR CAN CORRELATIONS BE MADE?

The first two holes on the Lazard tract were spaced only 200 feet apart. Since no difficulty was experienced in recognizing the different zones in these holes, later ones were spaced more widely—400, 600, and 1,000 feet. Toward the end of the investigation some were placed 2,000 feet apart, the zones still persisting so uniformly that their identification was never in doubt. As shown in the section (Fig. 2), the correlation was carried a total distance of 12,200 feet, and the same zones were picked up in other lines of holes parallel to this one. How far the zones might be carried cannot be determined from this investigation. It is probable, however, that heavy-mineral correlation would not be dependable over distances of many miles, at

[1] R. D. Reed, "Rôle of Heavy Minerals," *Econ. Geol.*, 1924, p. 745.

least not unless samples were available from a considerable number of intervening holes.

THE CORRELATION

As Figure 3 shows, the correlation proves itself. The zones are thick enough so that none was likely to be missed, and yet not so thick but that several could readily be penetrated. Our sampling methods, moreover, did not permit us to utilize the full sharpness of their boundaries. As in most geologic problems, there is, of course, an element of uncertainty in the results, but it is clearly not larger than that in most correlations. If the eight zones had merely an accidental order in one hole—and might equally well have any other order in a second hole, being lenses of

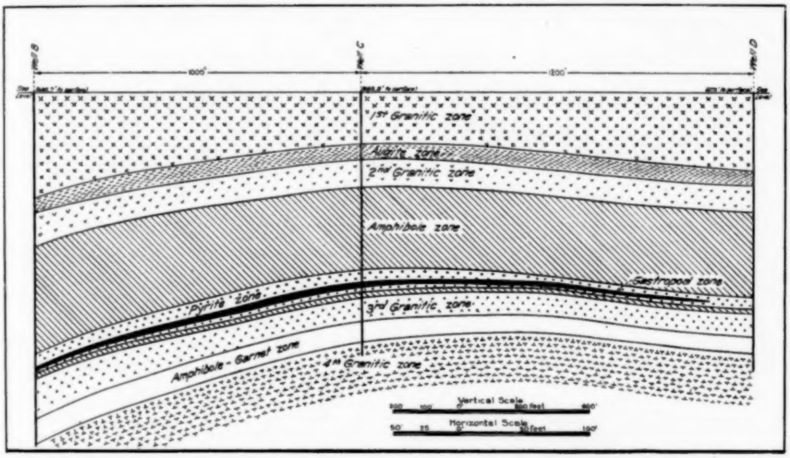

FIG. 3.—Details of the zones recognized in a small part of the Lazard tract. Notice that the section shows conditions only from sea-level down. Vertical scale exaggerated 4:1.

some peculiar type—what chance is there that the order in the second hole would be the same as that in the first? An algebraic formula teaches that there are more than 40,000 ways of arranging eight objects in a series, and the chance is therefore about 1 in 40,000. Several complications arise, of course, but none of them seems likely to reduce the odds to the danger point. And these odds refer to only two holes, while our correlation is based on samples from twenty-nine.

CONCLUSION

In this investigation the heavy minerals furnished the basis for a correlation far superior to any that could have been made by any other method known. This result seems to show that, given careful consideration of the geologic and engineering problems involved, some types of correlation problems may be confidently attacked by this method. Even under conditions less nearly ideal than those we found, there

is every reason to believe that sufficiently thorough study would give dependable results. Many wrong methods of procedure might nevertheless be devised, and the results already attained should not encourage anyone to undertake expensive projects without a thoroughgoing consideration of the many factors involved.

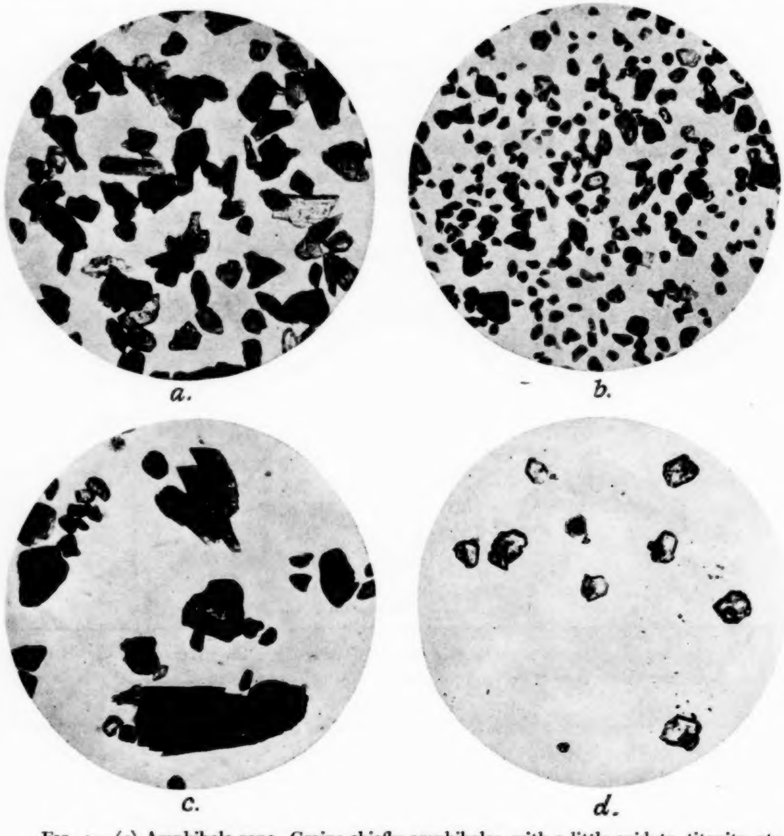

FIG. 4.—(*a*) Amphibole zone. Grains chiefly amphiboles, with a little epidote, titanite, etc. (*b*) A "granitic" zone. Zircon, garnet, magnetite, epidote, a little hornblende, etc. (*c*) Augite zone. Notice some very large augite grains with the usual jagged ends. (*d*) Barite grains. The grain marked *a* shows a common shape and the beveled edges; *b* has a clear border and clouded center, a very common arrangement. Magnification of *a*, *b*, *c*, 32 diameters; *d*, 18 diameters. Microphotographs made by Professor F. G. Tickell.

HEAVY-MINERAL DATA AT THE SOUTHERN END OF SAN JOAQUIN VALLEY[1]

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ABSTRACT

Results of a brief heavy-mineral investigation are offered here as a supplement to a contemporaneous paper by R. D. Reed and J. P. Bailey. It is shown that distinct stratigraphic variations in heavy-mineral content occur in late Tertiary sediments of the San Emigdio foothills, sediments which, from all indications, have been eroded from a single mountain mass of comparatively uniform petrographic character. It is concluded, therefore, that the practical value of heavy minerals for correlation is not restricted to conditions under which sediments have been derived from two or more petrographically distinct sources.

That heavy-mineral zones suitable for correlation purposes occur in some of the late Tertiary beds of the San Joaquin Valley has been demonstrated by the geologists of the Marland Oil Company of California.[2] In the case investigated, however, the zones found were considered to have resulted from the presence, in the source region, of two petrographically distinct areas. In deciding how widely the Marland methods could be used with success, we need the answer to at least one further question. Do stratigraphic variations in heavy minerals occur in sediments derived from a single land mass of comparatively uniform petrographic character? Data accumulated in the course of a study of the geology of the San Emigdio foothills, at the southern end of San Joaquin Valley, suggest the answer. These data will be presented here, at the suggestion of R. D. Reed, as a supplement to the preceding paper.

Cores taken from the Midland Oilfields Company well, on the north flank of Wheeler Ridge, afforded samples of subsurface Miocene strata.[3] Surface samples were taken from Pliocene rocks of the Etchegoin and Tulare formations of the same area.

RELEVANT GEOLOGIC FACTS

The San Emigdio Mountains, the highest parts of which lie about 10 miles south of Wheeler Ridge, have a central core of granitic rock which is continuous with that of the Tehachapi and Sierra Nevada mountains. This igneous mass is of

[1] Manuscript received by the editor, January 10, 1927. Published by permission of the Director, U. S. Geological Survey.

[2] R. D. Reed and J. P. Bailey, "Subsurface Correlation by Means of Heavy Minerals," this *Bulletin*, pp. 359–68.

[3] The writer is indebted to officials of the Midland Oilfields Co., Ltd., of Fellows, California, for permission to examine and sample these cores, and to Dr. Paul P. Goudkoff, of Los Angeles, for information concerning the age of microfossils contained in rocks penetrated by this well.

pre-Tertiary age, and, judged by the physical and petrographic character of the flanking sedimentary rocks, underwent erosion throughout most, if not all, of Tertiary time. In a petrographic investigation of many samples of Tertiary sediments from the San Emigdio foothills, nothing was found to indicate that any

TABLE I

ANALYSES OF NON-OPAQUE HEAVY-MINERAL CONTENT OF WHEELER RIDGE SEDIMENTS*

I. SUBSURFACE SAMPLES OF MIOCENE STRATA FROM WELL OF MIDLAND OILFIELDS COMPANY, LIMITED

Stratigraphic Depth	Zir.	Tit.	Hb.	Bio.†	Gar.	Tour.	Cor.	Epdt.	Bar.‡	Rut.
1,275	25	20	15	......	30	1	#	1	8	#
1,525	15	20	1	1	60	1	......	#	2	......
1,575	34	26	12	......	8	2	......	1	16	1
1,650	15	50	1	#	30	1	......	......	3	......
1,680	15	60	1	1	3	#	......	......	20	......
1,720	15	50	#	......	15	......	......	#	20	......
1,814	15	50	......	......	33	......	......	#	2	......
1,850	15	40	......	......	40	......	1	2	2	......
2,130	12	68	......	1	14	......	......	......	4	1
2,220	12	65	......	1	16	......	......	......	5	1
2,270	3	60	......	......	20	1	#	......	16	......

II. SURFACE SAMPLES COLLECTED FROM A MEASURED SECTION OF ETCHEGOIN AND TULARE FORMATIONS AND GIVEN IN ORDER FROM OLDEST TO YOUNGEST

No.	Zir.	Tit.	Hb.	Bio.†	Gar.	Tour.	Cor.	Epdt.	Bar.‡	Rut.
1	5	25	......	......	55	#	......	1	14	......
2	8	20	......	......	53	......	......	10	8	......
3	7	60	1	......	25	#	1	1	6	#
4	4	44	16	......	26	#	1	2	7	1
5	6	18	24	......	32	1	......	6	12	1
6	8	42	1	......	19	......	......	12	16	2
7	14	42	22	......	12	......	......	2	2	4

*Abbreviations:

Zir.—zircon
Tit.—titanite
Hb.—hornblende
Bio.—biotite
Gar.—garnet
Tour.—tourmaline
Cor.—corundum
Epdt.—epidote
Bar.—barite
Rut.—rutile
#—present but very scarce

Numbers in vertical mineral columns represent approximate percentages based on counts or estimates of grains in slides.

† Most of the biotite, noted as plentiful in surface exposures, was eliminated from the samples by panning.

‡ These barite fragments, occurring commonly in distinctly rhombic form, are probably not detrital grains; this mineral is apparently epigenetic in origin.

other land mass contributed detritus to this district during the Tertiary period. Although Miocene basaltic and andesitic rocks furnished some material for late Tertiary and Quaternary accumulations and a small amount of fine detritus may have been washed or blown in from adjoining regions, there is every reason to believe that such contributions were insignificant compared to the great quantity of rapidly accumulated sediment derived from the San Emigdio Mountains.

This mountainous range consists largely of granodiorite which is associated with rock types ranging from granite to diorite and including schist and gneiss in irregular and subordinate masses. All types of rock are similar in that they contain much the same minerals, although in different proportions. In this sense, the San Emigdio Mountains may be described as being of fairly uniform petrographic character. For all practical purposes, it may be said that late Tertiary sediments herein considered have been derived from a single source, a granitic mass which is fairly uniform, especially when compared with rocks exposed in the distributive provinces, or drainage areas, of most other basins.

Subsurface samples listed in Table I are of marine origin. Exposed Etchegoin beds of this area are largely lacustrine or marine, and grade upward into the Tulare formation, which was deposited to form alluvial plains and alluvial fans.

The preceding mineralogical analyses of surface and subsurface samples reveal distinct variations in the kind and percentage of non-opaque heavy minerals. One variation, that of the percentage of hornblende, is noticeable at a glance when inspecting slides of these mineral grains. Four distinct beds or zones, containing from 12 to 24 per cent hornblende, are separated by zones, apparently thicker, which are entirely free from this mineral or contain not more than 1 per cent. Important differences in the percentage of other minerals, such as titanite, garnet, and epidote, are obvious and should also prove useful for practical correlation purposes.

Continuous cores were not available from the Midland Oilfields Company well and the time available for this investigation did not permit examination of all cores and surface samples at hand. There are, therefore, wide gaps between individual samples, which, if filled in, would probably reveal other easily recognizable variations in mineralogy and would probably show that these variations can actually be detected within a very few feet stratigraphically.

POSSIBLE CAUSES OF VARIATIONS

The mineralogical character of sediments may be influenced by (1) the mineralogical character of the source rock, (2) climate, altitude, and topography during the erosion period, (3) distance and rapidity of travel and method by which sediments are transported and deposited, and (4) conditions which control the amount of alteration of mineral grains after deposition.

For detailed discussions of the relative importance of these factors under ordinary conditions, the reader is referred to previously published articles.[1] For the San Emigdio foothills, it is considered that the following factors, given in probable order of importance, have resulted in stratigraphic variations in the mineralogical character of accumulated sediments.

1. Variations in the local mineralogical character of the source rock. Such

[1] For the best article, see W. Mackie, "The Principles that Regulate the Distribution of Heavy Minerals in Sedimentary Rocks, as Illustrated by the Sandstones of NE. of Scotland," *Trans. Edin. Geol. Soc.*, Vol. 11 (1923), pp. 138–64.

variations probably occurred from place to place, and numerous changes in the type of rock exposed in a single drainage system may have occurred during the prolonged period of erosion.

2. Changes in the climate and topographic form of the land-mass as influenced by recurrent periods of uplift, and intervening, more stable periods of degradation. These factors may have provided for considerable variation in the degree of decomposition of ferromagnesian minerals and feldspars.

3. Variations in the velocities of transporting streams. It is possible that constant collision of rock and mineral fragments transported by swift streams resulted in an increase in the number of grains of those minerals, such as feldspar and hornblende, which have good cleavage. All mineral grains are very angular.

4. Irregularities in the sorting action of the surf and streams, resulting in local concentrations of magnetite, garnet, and possibly other heavy minerals. This factor may be more important than 3.

CONCLUSIONS

As far as they go, these data tend toward the conclusion that the usefulness of heavy minerals for correlation is not restricted to areas having accidental proximity to two or more petrographically distinct sources. Even though sediments of a district have, from all indications, been derived from a single land mass of comparatively uniform character, distinct stratigraphic variations in heavy mineral assemblages are to be expected.

SALT DOMES OF PERMIAN AND PENNSYLVANIAN AGE IN SOUTHEASTERN UTAH AND THEIR INFLUENCE ON OIL ACCUMULATION[1]

H. W. C. PROMMEL[2] AND H. E. CRUM[3]
Denver, Colorado, and Amarillo, Texas

ABSTRACT

This paper is based on personal, detailed studies in the field by the authors during a period of ten months in 1920, 1921, and 1926.

In it the authors summarize briefly the drilling activities and results obtained thereby in parts of southeastern Utah; they explain the age and mode of formation of salt domes in southeastern Utah and possibly in southwestern Colorado, and point to the relation of earlier periods of folding to post-Cretaceous folding. They also explain the relation of intense post-Cretaceous faulting to lines of salt cores encountered along the major axes of many of the superimposed anticlines of post-Cretaceous age. Possible subsurface conditions of deeper-seated, non-faulted salt domes or necks are described, and decidedly favorable geological conditions for the accumulation of oil and gas in large commercial quantities are mentioned. Recently mapped anticlines of the Green River Desert, which may interfere to some extent with the large gathering area of the Elk Ridge Anticline, are cited. The urgent need for more detailed, painstaking geological research work, in order to define periods of folding and uplift more accurately and to locate test wells more favorably, is pointed out. Actual occurrences in the region are cited, and maps, cross-sections, well logs, and photographs accompany the paper the better to prove and illustrate the conclusions.

The authors invite constructive criticism and discussion.

HISTORY OF DRILLING ACTIVITY

During the fall of 1918 and the spring of 1919 a well was drilled on the Salt Valley Anticline, Grand County, Utah. The well is located in the southeast corner of Sec. 5, T. 23 S., R. 20 E. (Fig. 2); it was drilled by Kendrick Levi of Green River, Utah, for the Wyoming Consolidated Company, to a depth of 825 feet. The well passed through 100 feet of gypsum, lime, and shale, 675 feet of shale and broken lime, and was abandoned after drilling through 50 feet of salt in which a small showing of oil and gas was obtained.

During the early part of 1920 a showing of oil in the Western Allies–Big Six Oil Company well just south of the town of Moab, in the NE. ¼ of Sec. 12, T. 26 S., R. 21 E. (Fig. 3), called attention to the oil and gas possibilities of southeastern Utah. This well passed through 635 feet of shale beds and 1,499 feet of salt. The salt beds increased in number and thickness with depth. This well was abandoned at a depth of 2,450 feet.

The showing of oil in this well led to the detailed mapping, in the spring of

[1] Read before the Association at the Denver meeting, September 23, 1926. Manuscript received by the editor, November 5, 1926.

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[3] Consulting geologist, Vineyard Manor, Amarillo, Texas.

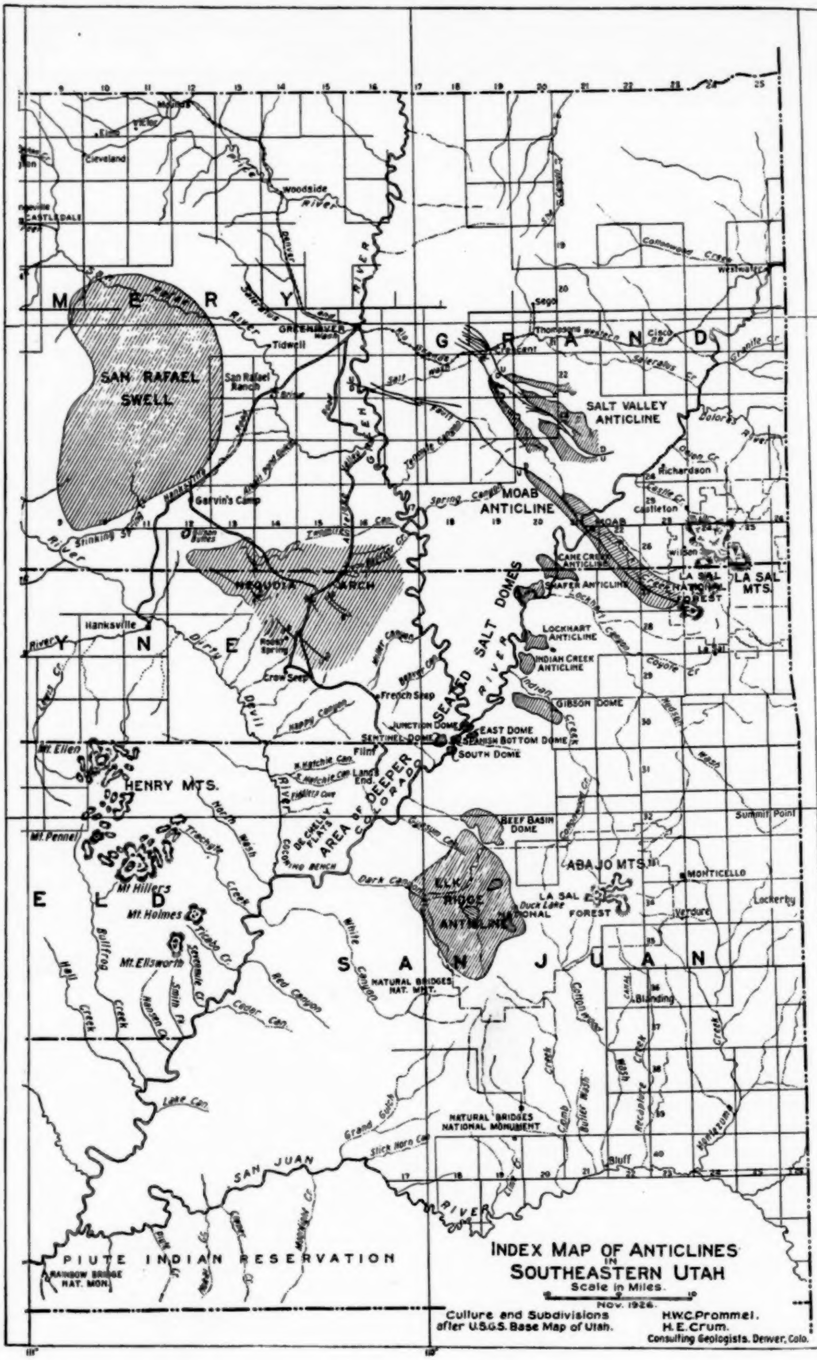

FIG. 1.—Map of southeastern Colorado showing anticlines discussed in this paper. (Copyright applied for.)

1920, of the Salt Valley Anticline (Fig. 2) by the senior author, under the direction of Fisher & Lowrie, and assisted by Kenneth B. Nowels and Roger F. White. It also caused him to look for a reported salt outcrop along Colorado River below Moab in order to explain the occurrence of massive salt bodies in the Moab well. On that trip the Cane Creek Anticline was noticed.

Encouraged by the showing of oil in their first well the Big Six Oil Company started a second well in 1920 in the NW. ¼ of Sec. 34, T. 25 S., R. 21 E. (Fig. 3)

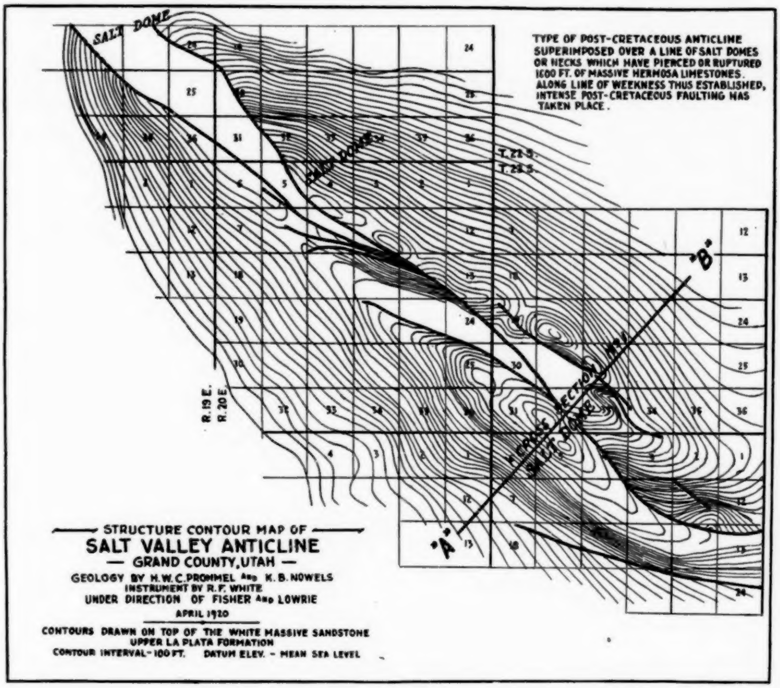

FIG. 2

on the west flank of the faulted Moab Anticline. This well had fourteen oil and gas showings at different horizons. Considerable bodies of salt increasing in number as well as in thickness were encountered in the lower part of this well. Attempts are now (1926) being made to drill the well deeper.

In 1921, the authors, under the direction of Fisher & Lowrie and assisted by Arthur J. Hazlewood, Earl Johnson, and John L. Shafer, mapped the Cane Creek, Shafer, Lockhart, and Indian Creek anticlines in detail (Fig. 4), called attention to the oil and gas possibilities of the lower Hermosa shale and possible sandstone series, and recommended the drilling of a test well.

The senior author has already described[1] the general stratigraphy and structure of parts of the Colorado River region in southeastern Utah and has called attention to several unconformities in the section.

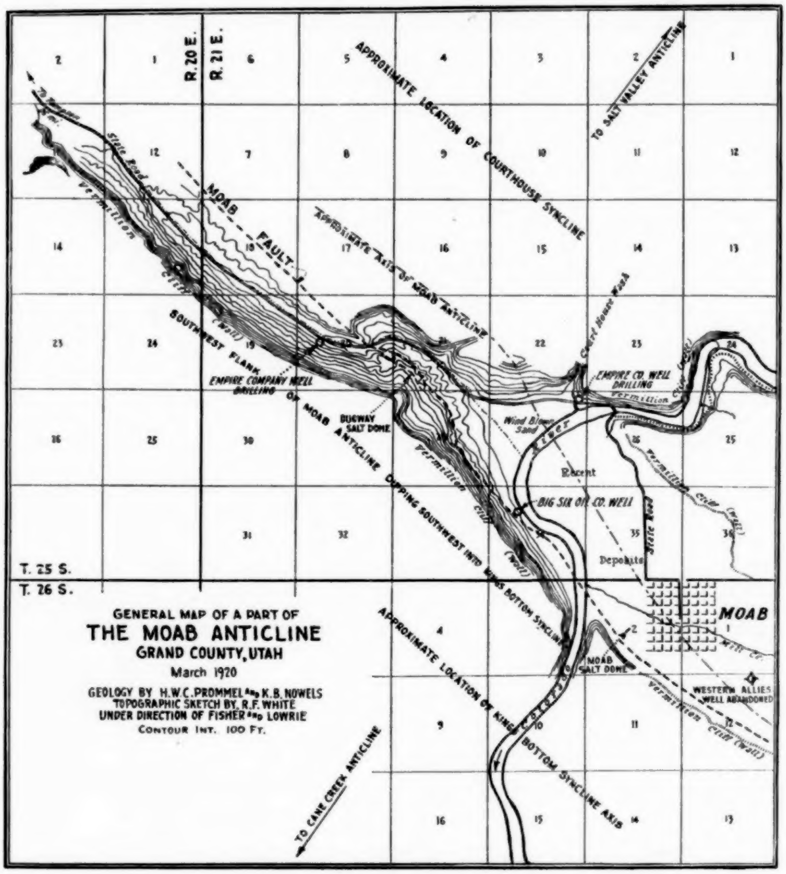

FIG. 3

Preparations for the drilling of a test well on the Cane Creek Anticline were started during the winter of 1924–25 by the Utah Southern Oil Company and the Utah Oil Refining Company. On December 8, 1925, the well drilled itself in at a depth of 2,028 feet, after having passed through several beds of salt. The oil and

[1] H. W. C. Prommel, "Geology and Structure of Portions of Grand and San Juan Counties, Utah," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), pp. 384–99.

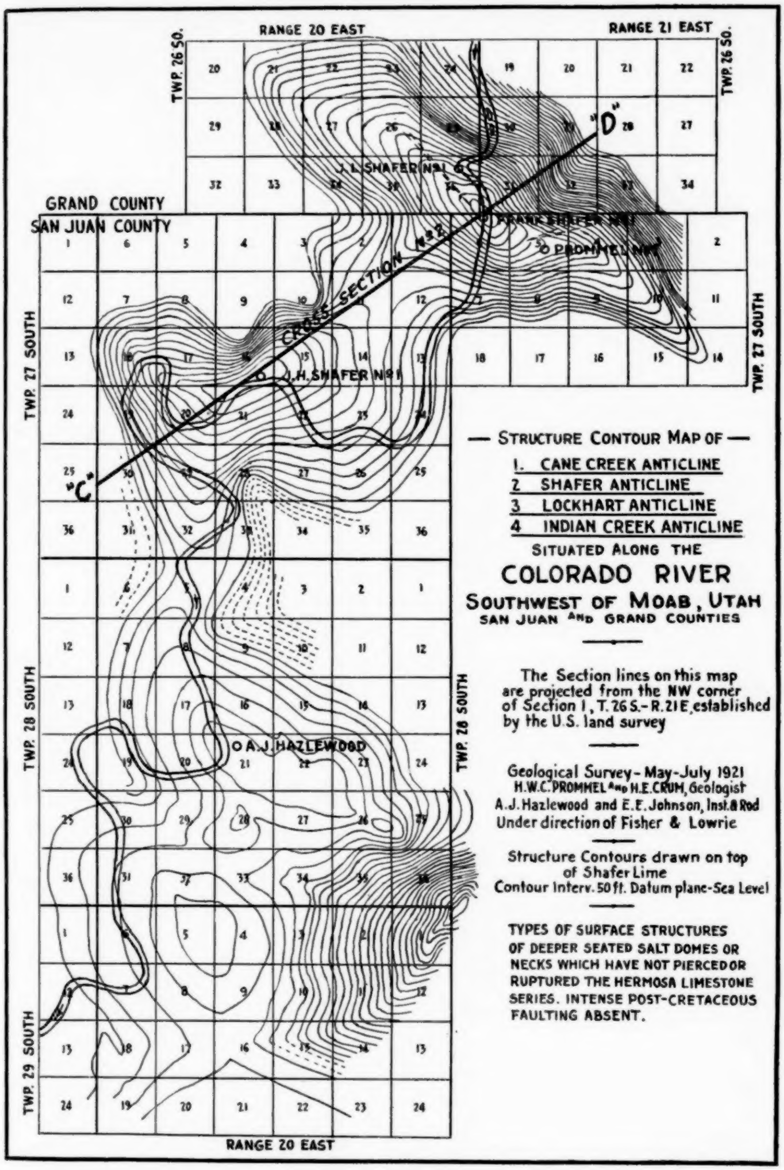
RANGE 20 EAST
RANGE 21 EAST
TWP. 26 SO.
TWP. 27 SOUTH
TWP. 28 SOUTH
TWP. 29 SOUTH
GRAND COUNTY
SAN JUAN COUNTY
"C"
"D"
CROSS SECTION No. 2
J. L. SHAFER No. 1
FRANK SHAFER No. 1
PROMMEL No. 1
J. H. SHAFER No. 1
A. J. HAZLEWOOD
— STRUCTURE CONTOUR MAP OF —
1. CANE CREEK ANTICLINE
2 SHAFER ANTICLINE
3 LOCKHART ANTICLINE
4 INDIAN CREEK ANTICLINE
SITUATED ALONG THE
COLORADO RIVER
SOUTHWEST OF MOAB, UTAH
SAN JUAN AND GRAND COUNTIES
The Section lines on this map are projected from the NW corner of Section 1, T. 26 S.-R. 21 E. established by the U.S. land survey
Geological Survey - May-July 1921
H.W.C. PROMMEL AND H.E. CRUM, Geologist
A.J. Hazlewood and E.E. Johnson, Inst. & Rod
Under direction of Fisher & Lowrie
Structure Contours drawn on top of Shafer Lime
Contour Interv. 50 ft. Datum plane-Sea Level
TYPES OF SURFACE STRUCTURES OF DEEPER SEATED SALT DOMES OR NECKS WHICH HAVE NOT PIERCED OR RUPTURED THE HERMOSA LIMESTONE SERIES. INTENSE POST-CRETACEOUS FAULTING ABSENT.
RANGE 20 EAST

FIG. 4

gas, which sprayed to a height of 300 feet or more above the derrick floor, ignited and burned the rig. The well flowed intermittently and the blaze was soon extinguished, but it took the better part of a month to bring it into control. A considerable amount of finely divided solid matter in the form of clay-mud and iron oxide was introduced under pressure into the well which, besides the oil, contained a supersaturated solution of salt. After two months of attempting to set casing and shut off the salt water of an upper horizon the well was again tested, without favorable results. Swabbing was resorted to and the well again flowed oil. A water shut-off had not been obtained, however, and the well, as it stood, was considered a small producer. Drilling was then continued. The log of the well (log No. 1) shows that 81 per cent of all formations passed through below 2,028 feet, to a depth of 3,747 feet, consisted of salt. From 3,628 feet to 3,642 feet, oil and gas were encountered, August, 1926, in a porous sandy lime and gray and black shale, and while casing was being set to shut off the lower, cavy shale, the oil rose 800 feet in the well. The well was then bailed down and a 10-foot core of dry shale was obtained. Below this depth 70 feet of salt were again encountered, and the well is now drilling in salt (September, 1926).

In March, 1926, a test well was started on the Shafer Anticline (Fig. 4). This well, upon reaching the base of the Hermosa limestones, commenced to encounter bodies of salt, increasing with depth. The well is now in sticky shale at a depth of 2,340 feet (log No. 2).

From 1921 to 1926 drilling was also carried on near Thompson's by the Crescent Eagle Oil Company on a very highly faulted part of the Salt Valley Anticline. This well was drilled to a depth exceeding 3,000 feet, and masses of salt and potash minerals were encountered in its lower part.

Since the first showing of oil and gas on the Cane Creek Anticline other test wells have been commenced on the Salt Valley, Moab, Cane Creek, Shafer, Lockhart, Gibson, Cedar Mesa, and Elk Ridge anticlines, and the drilling of additional test wells on other anticlinal structures within this region is under consideration.

From May to September, 1926, the authors made extensive geological studies in that part of Utah bounded by Green River on the northeast, Cataract Canyon of Colorado River on the east, southeast, and south, Fremont River on the southwest and west, the San Rafael Swell on the northwest, and the Denver and Rio Grande Western Railroad on the north.

PROBLEMS OF ORIGIN AND AGE

Thomas S. Harrison[1] first pointed to the possible existence of salt domes in southeastern Utah. The authors believe that salt domes do exist but they are at variance with Harrison's theory of origin and age of these salt domes (Figs. 5, 6, 7, and 9).

There are at present widely divergent opinions among geologists and operators

[1] "Colorado-Utah Salt Domes" (paper read before the Dallas meeting of the American Association of Petroleum Geologists, March, 1926), this *Bull.*, Vol. 11 (1927), pp. 111–33.

A

B

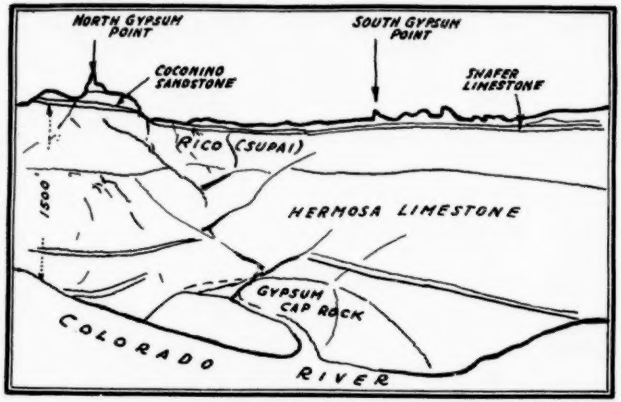

FIG. 5.—*A*, a salt dome in Cataract Canyon; *B*, diagram of salt dome shown in *A*

A

B

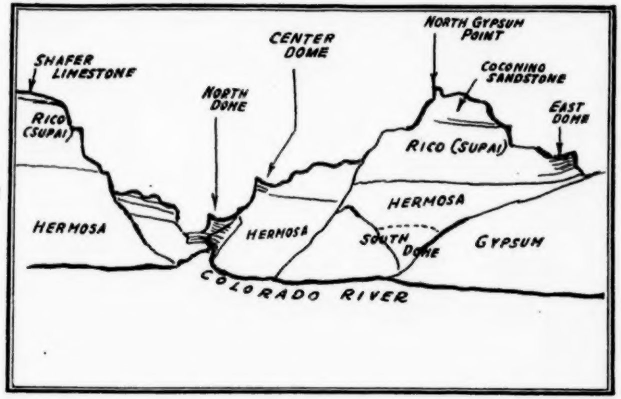

FIG. 6.—*A*, salt domes in Cataract Canyon; *B*, diagram of salt domes shown in *A*

regarding stratigraphic and structural conditions, periods of folding, and extensive oil accumulation in southeastern Utah.

After ten months of personal study in the field the authors have come to tentative conclusions and offer explanations regarding different periods of folding, the origin of the salt domes or necks, and the possible accumulation of oil and gas in large commercial quantities in the Permian and Pennsylvanian strata of southeastern Utah. Similar conditions may exist in southwestern Colorado. The authors do not consider their conclusions and explanations final. Sidney Powers, in his paper on reflected buried hills in the oil fields of Persia, Egypt, and Mexico,[1] points out many subsurface possibilities, some of which may also confront the

FIG. 7.—Reflection of salt dome in Cataract Canyon

geologist and operator in southeastern Utah as exploration and development progress.

Possible subsurface conditions as interpreted by the authors may be found even more complicated. They convey what they actually observed in the field, and their ideas and theories are based principally on actual occurrences in parts of southeastern Utah.

That doming of gypsum and possibly of salt exists in southeastern Utah is shown to best advantage in a part of Cataract Canyon of Colorado River (Fig. 5), where a mass of gypsum exhibiting flowage lines is exposed on the east bank of the river, with a maximum height of nearly 300 feet above the river bed. A line drawn across this gypsum mass at the level of the river is more than 3,000 feet in length. Hermosa limestones dip away at steep angles in all directions from the

[1] Sidney Powers, "Reflected Buried Hills in the Oil Fields of Persia, Egypt, and Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 4, April, 1926.

central gypsum mass, and the dips toward Elk Ridge are as high as 30 to 40 degrees next to the gypsum. At a short distance from the gypsum the dips decrease in amount and are in fact very gentle, indicating a gentle, gradual uplift of the Hermosa series before a part of it was pierced or ruptured by the gypsum. Similar gypsum masses are exposed at Moab and in Salt Valley, where they have been intruded much higher into the overlying beds and where formations of Triassic age overlap on the gypsum. At these localities the entire Hermosa series has been pierced or ruptured by the gypsum intrusion, but is present along its flanks as will be proved on another page of this paper. Similar conditions, the authors believe, are encountered in southwestern Colorado, in Sinbad and Paradox valleys. One of the problems to be solved is the determination of the age of southeastern Utah salt domes. Harrison[1] has advanced the theory that the warping is due to loading, to the heavy canyon walls pressing into buried salt beds causing the salt to flow into the area of relief. This theory is probably based on conditions encountered at "Culebra Cut" during the building of the Panama Canal. The bottom of the canal warped upward due to the side loading after the material along the line of the canal had been removed. Actual conditions observed in Cataract Canyon by the authors do not bear out Harrison's theory for southeastern Utah salt domes, but seem to reverse it.

In Cataract Canyon (Fig. 9) there is a gypsum plug (Fig. 5) very probably underlain by salt, which formed an obstruction to the river and diverted it from its course. This obstruction must have been a pronounced topographic high during a considerable period of time but was gradually reduced in size by back-cutting of the river meanders, which finally joined as shown in Figure 9. The authors believe that the salt domes determined the course of Colorado River through Cataract Canyon, rather than the river being the cause of folds or warps along its course and in areas adjacent thereto. Reflections of gypsum and possible salt domes were noticed from the junction of Colorado and Green rivers, a distance of 25 miles southwestward, in Cataract Canyon as well as in some adjacent areas. A statement made in *U. S. Geological Survey Water Supply Paper 556*[2] is of interest and is quoted herewith:

> As a result of detailed surveys and diamond-drill borings, the Bureau of Reclamation in 1914 reported unfavorable foundation conditions for a dam immediately below the mouth of the Green River. Although a careful examination was made, no dam sites were found near the head of this canyon. On account of wide sections and unfavorable rock structure, a feasible dam site was not found until 30 miles of the canyon below Green River had been surveyed.

The authors of this paper believe that southeastern Utah salt domes were formed contemporaneously with folding of the formations which now directly overlie, are intruded by, and underlie the salt domes. The age of this folding is

[1] *Op. cit.*

[2] E. C. LaRue, "Water Power and Flood Control of Colorado River below Green River, Utah," *op. cit.*, 1925.

late Pennsylvanian (Aubrey-Rico) and late Permian (near close of Moenkopi deposition). These salt domes or necks were intruded by flowage of salt and gypsum along crevices and fractures, at and near the apices of forming anticlines, into the overlying formations, some of which they pierced or ruptured, the height of intrusion depending on local conditions in each case.

The Triassic overlap and Permian unconformity which are so well exposed at Moab (Fig. 8) and at other places in southeastern Utah have been known many years and have been described by Cross,[1] but their relation to the peculiar arch-like gypsum masses exposed in the Moab Valley, at Salt Valley, and several other places in southeastern Utah and southwestern Colorado (which, if occurring above the Hermosa limestone series, are always associated with intense post-Cretaceous faulting), has never been satisfactorily explained. Some confusion has existed be-

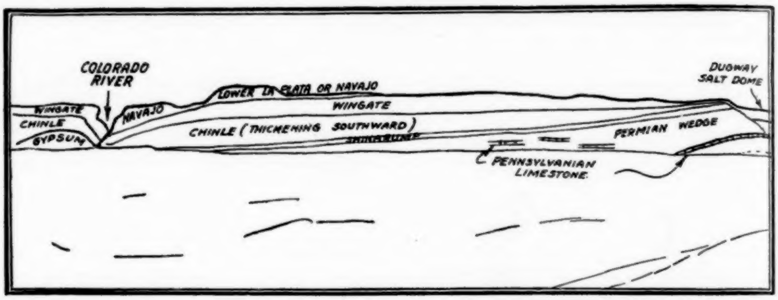

FIG. 8.—Triassic overlap and Permian wedge on west side of Moab Valley

cause of the presence here and there of a series of well-bedded gypsum layers in the upper part of the Permian, such as are exposed on the flank of the San Juan anticline. The authors believe that Cross's opinion that these upper gypsum beds were in places eroded before the Triassic conglomerates (Shinarump) were laid down unconformably over the truncated Permian beds is correct. The observations by Cross which were checked in the field by the senior author, assisted by Kenneth B. Nowels and Roger F. White (three sections were carefully measured from the bottom of Moab Canyon to the base of the Wingate cliff), are of such importance relative to the possible age of the salt domes or necks of southeastern Utah and southwestern Colorado that the authors quote from his paper:

That in this vicinity a stratigraphic break of much importance occurs just below the "Saurian Conglomerate," as it has been called in the San Juan Region, is evident on Grand River (now Colorado River) and at other places. On the west side of Grand River opposite Moab the bone-bearing conglomerate is separated from fossiliferous Pennsylvanian beds by only 50 feet of shaly sandstone, and it is possible that these beds also

[1] Whitman Cross, "Stratigraphic Results of a Reconnaissance in Western Colorado and Eastern Utah," *Jour. Geol.*, Vol. 15 (Oct.-Nov., 1907), p. 634.

belong to the Pennsylvanian series. . . . . Near Moab, on the northeast side of Spanish Valley, a poorly exposed section reveals about 250 feet of strata, mainly reddish sandy shales, between the "Saurian Conglomerate" and the uppermost Pennsylvanian limestone. On Grand River about 1 mile above the Moab ferry, the "Saurian Conglomerate" reappears above the level of the river, and, as it rises gradually to the northeast for several miles, a larger and larger section of the pre-Dolores strata is exposed, but nowhere, so far as our observations go, do the Pennsylvanian beds appear, all the sub-Dolores section belonging to the upper (Permian ?) series of the Carboniferous. This is itself evidence of a great break immediately below the "Saurian Conglomerate." That the break represents uplift and erosion producing angular unconformity is well illustrated on both sides of Grand River about ten or twelve miles northeast of the ferry and just below the mouth of Castle Creek . . . . this unconformity may be traced for about half a mile, and it was estimated that at least 600 or 800 feet of beds are visibly truncated by the conglomerate

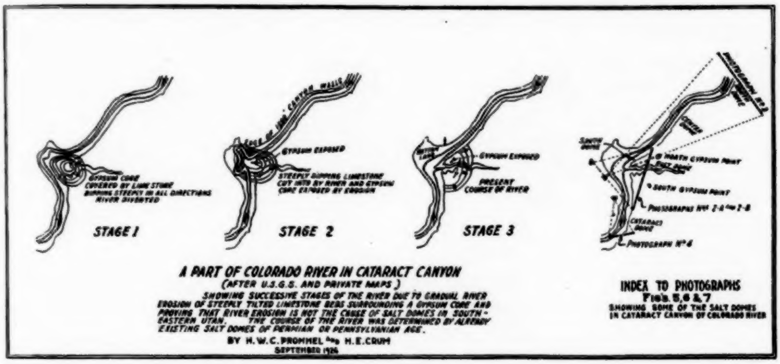

FIG. 9

in one continuous exposure. The occurrence of an extensive section of gypsiferous sandstones and shales beneath the Dolores conglomerate in Fisher Valley on the northwest side of the La Sal Mountain adds so much to the beds transgressed; and a still higher series of sandstones and conglomerates is known, so that, altogether, it is estimated that not less than 1,500 and possibly 2,000 feet of Permian (?) or upper fossiliferous Pennsylvanian beds have been eroded in the locality of the section first mentioned, opposite Moab [Fig. 8].[1]

The authors of this paper at first believed that the early folding took place mainly during Rico-Aubrey time, and on the cross-section of Salt Valley Anticline they show the Permian beds overlapping the Rico formation (Fig. 10). Some folding and uplift may have taken place at that time, as the relation of the Rico to the overlying Permian beds is not clear at Moab in the vicinity of the gypsum mass on the west side of Moab Valley. The observations of Cross show, however, that the Permian beds were involved in early uplift and later subjected to erosion so that

[1] *Op. cit.*

the Triassic conglomerates (Shinarump) rest on the truncated edges of the Permian.

This Triassic overlap appears to be everywhere pronounced in the vicinities where arch-like gypsum masses occur unconformably well above the Hermosa limestone section in the sedimentary series. Likewise, the Permian beds everywhere increase in thickness away from these arch-like gypsum masses. These observations lead the authors to believe that the gypsum masses represent the caprocks of salt domes or salt necks of late Pennsylvanian or more probably of late Permian age, which at one time existed as islands or structural hills, subjected to erosion before Triassic beds were laid down; they may occupy the lines of still earlier folding.

Within the area under discussion the salt domes present may be divided into two groups: those which have pierced or ruptured the Pennsylvanian Hermosa limestone series, and those which did not pierce, or only partially pierced or ruptured, this massive limestone series. Representatives of both groups may be present within the core of the superimposed anticline of post-Cretaceous age. This may be the case on the Moab Anticline, where at least two salt domes or necks are present. In the vicinity of the "Dugway" (Fig. 3) highly arched Hermosa limestones suggest a salt core underneath them. They may, however, also represent the pierced edges of the Hermosa series on the flank of a salt core or salt neck, the salt being down-faulted to the east.

Just south of where Colorado River passes through the Wingate cliff, on the west side of Moab Valley, an arch-like gypsum mass is overlain by Triassic beds. At this place the Hermosa limestones have been pierced or ruptured by the gypsum and salt and possibly also by a part of the shale member which underlies the Hermosa limestones. If this is actually the case, and taking into consideration the Moab fault, a well drilled east of the gypsum mass should not encounter any massive limestone series; a well drilled between the gypsum mass south of the river and the "Dugway" salt dome or neck (Fig. 3) north of the river should encounter the Hermosa limestone in place; and a well drilled in the vicinity of the "Dugway" salt dome may, or may not, encounter Hermosa limestones.

Actual drilling proves these contentions. The Western Allies well in Sec. 12 (Fig. 3) found only gray and black shale, and salt. The well now being drilled on the east side of Moab Valley, at the Moab power and light plant, very near another arch-like gypsum mass, drilled through 1,000 feet of black and gray shale without encountering the Hermosa limestones; the Big Six Oil Company in Sec. 34, between the two salt domes previously mentioned and possibly on one side of a line connecting the apices of the domes, found the Hermosa limestone series in place. Similarly, the core of the Salt Valley Anticline is formed by a series of salt domes or necks which have pierced the Hermosa limestones so that these limestones should be absent in the middle of the valley; in fact, the Wyoming Consolidated Oil Company well *did* fail to find these massive limestones and went into salt at a depth of 775 feet.

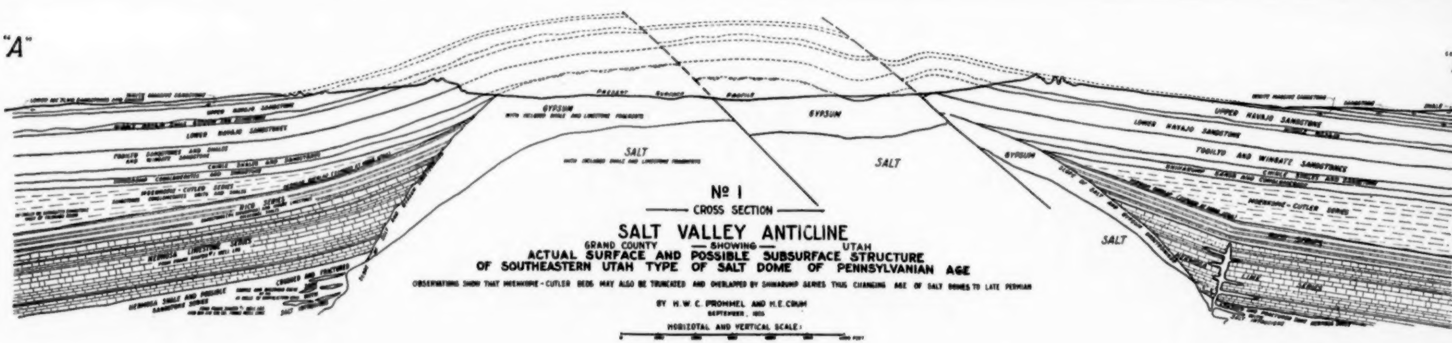
"A"
"B"
Nº 1
CROSS SECTION
SALT VALLEY ANTICLINE
GRAND COUNTY
SHOWING
UTAH
ACTUAL SURFACE AND POSSIBLE SUBSURFACE STRUCTURE
OF SOUTHEASTERN UTAH TYPE OF SALT DOME OF PENNSYLVANIAN AGE
OBSERVATIONS SHOW THAT MOENKOPIE-CUTLER BEDS MAY ALSO BE TRUNCATED AND OVERLAPPED BY SHINARUMP SERIES THUS CHANGING AGE OF SALT DOMES TO LATE PERMIAN
BY H.W.C. PROMMEL AND H.E. CRUM
HORIZOTAL AND VERTICAL SCALE:
GYPSUM
SALT
UPPER NAVAJO SANDSTONE
LOWER NAVAJO SANDSTONE
TODILTO AND WINGATE SANDSTONES
MOENKOPIE-CUTLER SERIES
RICO SERIES
HERMOSA LIMESTONE SERIES

Fig. 10

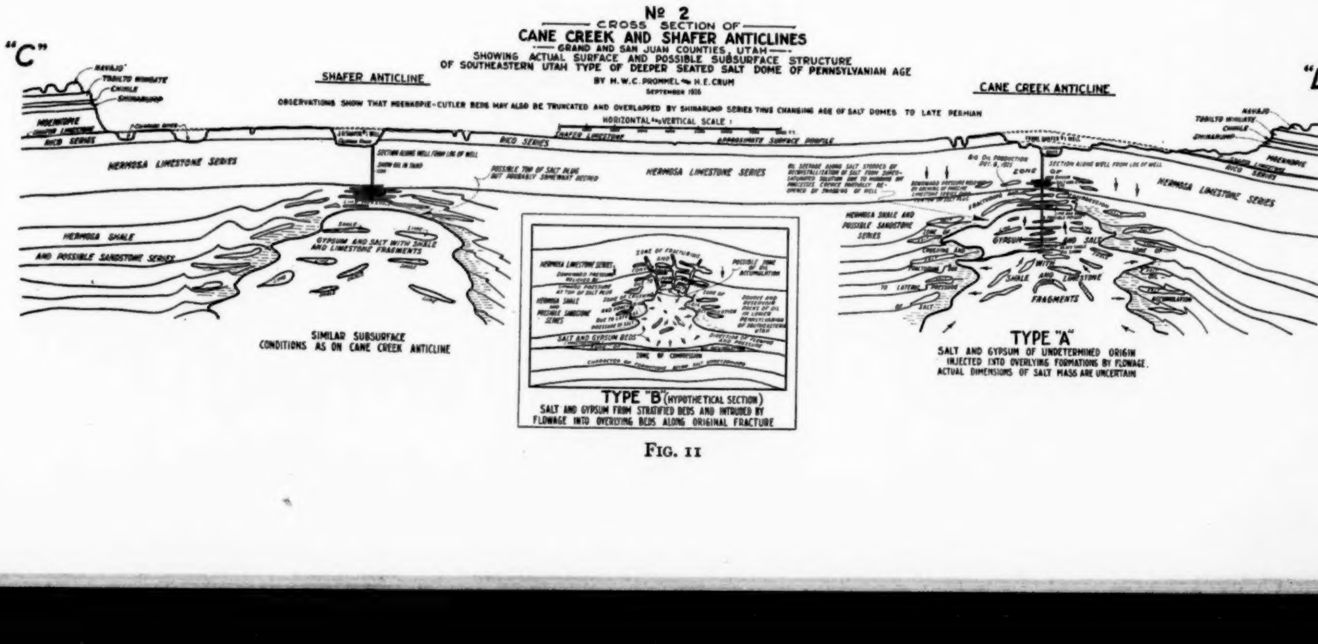
Nº 2
CROSS SECTION OF
CANE CREEK AND SHAFER ANTICLINES
GRAND AND SAN JUAN COUNTIES, UTAH
SHOWING ACTUAL SURFACE AND POSSIBLE SUBSURFACE STRUCTURE
OF SOUTHEASTERN UTAH TYPE OF DEEPER SEATED SALT DOME OF PENNSYLVANIAN AGE
BY H.W.C. PROMMEL AND H.E. CRUM
SEPTEMBER 1926
OBSERVATIONS SHOW THAT MOENKOPIE-CUTLER BEDS MAY ALSO BE TRUNCATED AND OVERLAPPED BY SHINARUMP SERIES THUS CHANGING AGE OF SALT DOMES TO LATE PERMIAN
"C"
"D"
SHAFER ANTICLINE
CANE CREEK ANTICLINE
NAVAJO
TODILTO WINGATE
CHINLE
SHINARUMP
MOENKOPIE
RICO SERIES
HERMOSA LIMESTONE SERIES
HERMOSA SHALE
AND POSSIBLE SANDSTONE SERIES
GYPSUM AND SALT WITH SHALE AND LIMESTONE FRAGMENTS
SIMILAR SUBSURFACE
CONDITIONS AS ON CANE CREEK ANTICLINE
TYPE "B" (HYPOTHETICAL SECTION)
SALT AND GYPSUM FROM STRATIFIED BEDS AND INTRUDED BY
FLOWAGE INTO OVERLYING BEDS ALONG ORIGINAL FRACTURE
TYPE "A"
SALT AND GYPSUM OF UNDETERMINED ORIGIN
INJECTED INTO OVERLYING FORMATIONS BY FLOWAGE.
ACTUAL DIMENSIONS OF SALT MASS ARE UNCERTAIN

Fig. 11

RELATION OF POST-CRETACEOUS FAULTING TO SALT CORES OF OLDER AGE

In the foregoing paragraph the authors have explained that some of the salt domes or necks have pierced or ruptured the massive Hermosa limestone series. The Moab Valley and Salt Valley salt domes belong to this group, but the Cane Creek, Shafer, Lockhart, Indian Creek, Gibson, Beef Basin, and other anticlines south and west of the Moab Anticline belong to the group which have not pierced the Hermosa although the salt masses of some of this group have partially intruded the lower beds of the limestone series (Figs. 5, 10, and 11). Intense post-Cretaceous faulting is everywhere associated with the former group, but post-Cretaceous faulting is negligible in, or absent from, the latter group. It has already been pointed out that lines of salt cores, salt domes, or salt necks over which the massive limestone series is absent, exist along the major axes of the Salt Valley and Moab superimposed post-Cretaceous anticlines. It is therefore reasonable to assume that the intense post-Cretaceous faulting followed the lines of least resistance, offered by the zones where the Hermosa limestone series is absent and where shales, some sandstones, and gypsum and salt only are present. The large faults on Salt Valley Anticline and on Moab Anticline, as well as on other large superimposed anticlines of post-Cretaceous age in southeastern Utah and southwestern Colorado, will therefore probably be found to have salt domes or salt necks at their bases and will not in any way affect the tilted and crushed beds along the irregular flanks of salt domes (Fig. 10). This is of great importance with respect to possible oil accumulation along the flanks of those anticlines on which the central salt cores have ruptured or pierced the Hermosa limestone series.

From the foregoing discussion the authors believe that anticlines in southeastern Utah, and possibly in southwestern Colorado, even though they exhibit intense post-Cretaceous faulting paralleling in a general way their major axes, are worthy of test wells along their flanks to prove the presence or absence of oil in commercial quantities. The drilling of test wells along the major axes of highly faulted, superimposed post-Cretaceous anticlines on which gypsum appears at the surface or may occur very near the surface must be classed as a hazardous undertaking at this time.

SUBSURFACE CONDITIONS OF DEEPER-SEATED, NON-FAULTED SALT DOMES OR NECKS

Possible subsurface conditions on anticlines with central salt cores which have not ruptured or pierced the Hermosa limestone series are shown and explained on cross-section No. 2. Conditions as shown are based on actual surface structure and on the logs of the Frank Shafer and John H. Shafer wells. If the salt and gypsum mass was intruded into the formations by flowage it must be assumed that this mass was in a semi-liquid state and that hydrostatic pressure was directed equally in all directions. But the effect of compressional stresses in beds of different composition and therefore of different resistance must be taken into

consideration. In all cases, due to the upward thrust of the salt along lines of least resistance, the massive Hermosa limestone series seems to have been gently arched a considerable distance away from the sides of the salt core. This in turn relieved the downward pressure caused by the massive limestones along the sides of the salt core, and allowed lateral thrust of the salt to crumple, fracture, and intrude the comparatively soft shales and possible sandstones underlying the Hermosa.

OIL OCCURRENCE AND OIL ACCUMULATION

The production of oil from the Frank Shafer No. 1 well proves that the lower Hermosa shale and possible sandstone series are petroliferous. Formations which have produced oil and gas in large quantities may underlie the Pennsylvanian unconformably in southeastern Utah and may give rise to a second producing horizon which even now may contribute to the possible oil accumulation on top of the deeper-seated salt domes, and on the flanks of deeper-seated as well as highly faulted salt domes of southeastern Utah and southwestern Colorado. If it should prove possible to drill through the central core of salt (hypothetical section, type B, Fig. 11), folded beds capable of oil production may even be found underneath the salt series from which the salt domes or necks may have originated. No evidence exists at present, however, which could either deny or assure such possibilities.

Even though no sandstones were present in the lower Hermosa shale member the fractured, crumpled, and intruded shale along the flanks of the irregular salt domes may give rise to a reservoir zone in all directions from the central salt core.

Natural-gas seeps occur along Green River at its junction with Colorado River. These gas seeps are located on the flank of a salt dome which is reflected in the overlying Hermosa limestones.

Exact boundary lines of the Pennsylvanian Embayment region of southwestern Colorado and southeastern Utah cannot as yet be definitely established, but field work done by the authors in the area discussed in this paper convinces them that anticlinal structures and possibly deeper-seated salt domes, on which the Rico series as well as the oil-saturated De Chelly sandstone of Permian age are under cover, exist within this region which has been described by some geologists as a part of the large gathering area of the Elk Ridge Anticline. To judge from their work in the Sweetwater area, Conley's Nequoia Anticline of the Green River Desert, though incorrectly interpreted by him, may not be as great a myth as it has constantly been pointed out (Fig. 1). The authors believe that, due to insufficient detailed field work within the gathering area lying northwest of Elk Ridge Anticline, this gathering area might easily be overestimated and will be interfered with to some extent by salt domes northwest of Elk Ridge Anticline. If conditions for accumulation of oil and gas on Elk Ridge Anticline are considered as favorable, the same, if not more favorable, conditions may be expected on the "down dip" anticlines or salt domes lying to the northwest.

As Jurassic and Triassic formations cover the anticlines of the Green River Desert a test well on one of these structural highs will furnish valuable informa-

tion, as it will show to what extent the Permian beds have been eroded over the top of earlier anticlinal folding. The amount of erosion of the Permian will probably vary on different anticlines.

The authors of this paper believe that, on account of the close nesting of salt domes in southeastern Utah, especially along, and adjacent to, Colorado River and a part of Green River, a region of general uplift is present within the Pennsylvanian Embayment region in which geological conditions appear to be decidedly favorable for the accumulation of oil and gas in large commercial quantities. Southeastern Utah is important from the standpoint of geological research work, and it will no doubt furnish its share of information to make Geology a more exact science than it is today.

SUBSEQUENT NOTE

Since this paper was written fossils classified by the geological department of the Midwest Refining Company, Denver, as Silurian have been found in the Frank Shafer No. 1 well on the Cane Creek Anticline in black shale at a depth of 3,600 feet. This shale is overlain and underlain by salt and is probably a shale inclusion which has moved upward with the salt, from its original position in the sedimentary series.

According to J. B. Reeside, Jr.,[1] paleontologist of the U. S. Geological Survey, fossils of Devonian age are present along the faulted zone of the Salt Valley Anticline in a sandstone and limestone breccia. This outcrop is located near the Western Allies well.

The presence of these fossils, far above their normal position in the geological column, in inclusions and fault breccia, is deemed of great importance by the authors, as it strongly points to deep-seated origin of the salt and gypsum masses which now form the salt domes of southeastern Utah and southwestern Colorado.

DISCUSSION

H. W. C. Prommel: I wish to call attention to the different specific gravities of the rocks on the Cane Creek Anticline. At the apex of the Cane Creek Anticline 1,300 feet of massive Hermosa limestone, which has the highest specific gravity and is the most resistant formation in the geologic column in southeastern Utah, still underlies the river bed. The formations occupying the cliffs surrounding this structure and overlying the limestones are composed of sandstone and shales of much lower specific gravity and have a thickness of only 1,500 feet. I cannot believe that an added thickness of only 1,500 feet of soft sandstones and shales lying upon highly resistant limestones of almost equal thickness constitutes sufficient additional load to cause flowage of the salt and also produce arching in this resistant series, as set forth by Mr. Harrison.

C. A. Fisher: What formations lie at the surface on and near the anticlinal structures northwest of the Elk Ridge Anticline?

H. W. C. Prommel: Jurassic, Triassic, and Upper Carboniferous.

[1] Oral communication from C. E. Dobbin, U. S. Geol. Survey, to H. E. Crum, September 20, 1926.

From Cataract Canyon, where the Hermosa and Rico formations form a nearly vertical cliff 1,500 feet high, the formations dip northwest. The Coconino sandstone overlies the Rico in this region and its belt of outcrop, in which some anticlinal structures are present, is 12 miles wide. This is followed by the Moenkopi, containing the somewhat lenticular, highly cross-bedded in its upper part, oil-saturated De Chelly sandstone. The Moenkopi is overlain by the Shinarump sandstone and conglomerate which is a bench-maker in this region. Above this bench rises the Chinle slope which is topped by the Wingate and Todilto series. The formations described form the slopes and cliffs between the Green River Desert plain and the canyon of Colorado River.

Farther northwest, where the normal dips of the formations carry them to a lower level, the Navajo, Carmel (middle Navajo), and Entrada sandstone (upper Navajo) form the canyons below the Green River Desert plain.

The formations which lie at the surface on the Green River Desert anticlines range from the Wingate to the lower McElmo formation. The formations on these anticlines lie above the oil-bearing De Chelly sandstone, and above the Rico, or Supai, formation, which shows at least three oil-bearing sandstones in Cataract Canyon of Colorado River and has produced oil in commercial quantities in the San Juan field of southeastern Utah, and above the Pennsylvanian petroliferous Hermosa series, all of which are within reach of the drill.

A series of northwest-southeast trending faults with small displacements traverses this region from Cataract Canyon of Colorado River to the San Rafael swell. Oil is associated with these faults.

LOG NO. 1

Log of Well on Shafer Anticline, Utah

CASING RECORD

150 ft. 3 in. of $15\frac{1}{2}$-in.
698 ft. 10 in. of $12\frac{1}{2}$-in.
1,740 ft. of 10-in.

J. H. Shafer No. 1—Midwest Exploration Company
SE. $\frac{1}{4}$ Sec. 16, T. 27 S., R. 20 E.
800 ft. from E. line, 700 ft. from S. line of section
Commenced: March 12, 1926
Completed:

Total Depth in Feet through Each Formation	Formation	Total Depth in Feet through Each Formation	Formation
20	Blue lime—crevices	334	Blue shale and gray limestone
25	Blue lime and boulders	350	Hard dark lime—very hard
63	Red sand—water at 45	365	Black slate
78	Hard brown lime	375	Black lime
81	Water sand	414	Very hard gray lime, dark
100	Red muddy shale	425	Black shaly lime
110	Hard brown lime	440	Gray sandy lime
129	Blue shale	465	Muddy gray sand
130	Hard shell	470	Hard sharp lime

LOG NO. 1—*Continued*

Total Depth in Feet through Each Formation	Formation
485	Hard gray sandy lime
525	Muddy sand and chocolate shale
565	Gray limestone, sandy
590	Brown shale
605	Interbedded dark brown limestone and shale
625	Shelly sand, limestone, and shale
670	Blue shale and gray limestone
680	Shelly blue shale
685	Sand
718	Gray limestone and gray and brown shale
724	Water sand—fresh sulphur water
753	Gray sandy lime
764	Blue sticky clay
782	Sand—slight show of oil and salt water
890	Gray shale and limestone, sandy in places
908	Gray limy sand
1,155	Light and dark gray limestone and streaks of shale
1,175	Black lime—coarse
1,180	Sticky blue shale
1,286	Light and dark gray limestone
1,322	Gray limestone and shale
1,362	Hard black lime
1,483	Light and dark gray limestone, hard and sharp
1,504	Dark gray limestone and shale
1,565	Hard black limestone and shale
1,577	Dark gray lime
1,610	Gray lime with streaks, sandy shale
1,620	Streaks salt lime
1,625	Muddy salt
1,635	Salt and shells
1,734	Salt
1,735	Lime shell
1,745	Lime
1,755	Brown muddy sand
1,770	Black slate
1,788	Black running shale
1,796	Hard black lime
1,800	Salt and gray lime
1,820	White lime and salt
1,830	White lime
1,899	Salt
1,905	Gray lime
1,938	White rotten lime
1,990	Black soft shale
2,050	Salt
2,075	Rotten lime
2,094	Gray sandy shale
2,100	Lime shell hard
2,125	Gray sandy shale
2,255	Salt
2,270	Lime
2,320	Gray shale

LOG NO. 2

Log of Cane Creek Well, Grand County, Utah

CASING RECORD

64 ft. 6 in. of 20-in.
891 ft. of 15½-in. cemented
1,413 ft. of 12½-in. cemented
2,024 ft. of 8¼-in.
3,206 ft. 10 in. of 6¼-in. cemented

Shafer No. 1—Midwest Exploration Company
NE. ¼ Sec. 6, T. 27 S., R. 21 E., Cane Creek, Grand County, Utah
2, 035 ft. from E. line of section, 625 ft. from N. line of section
Elevation: 4,003 ft.
Commenced: April 11, 1925
Completed: March 11, 1927

Total Depth in Feet through Each Formation	Formation
25	Sandstone and surface formation
55	River sand—water
63	Gray shale
70	Gray limestone—very hard
83	Grayish-brown sand—water
85	Light gray shale
95	Sand
115	Gray shale
130	Limestone
140	Brown sandy shale
150	Brown sand
162	Brown shale
186	White limestone, very hard
200	Gray shale
217	White limestone—very hard
219	Brown sand
237	Brown shale
390	Interbedded gray shale and limestone
404	Brown sand
431	Gray sandy limestone—hard and abrasive
438	Brown sandy limestone
895	Gray limestone with some shale beds
902	Hard black lime
909	Gray lime—very hard
910	Blue shale
919	Hard white lime, fine
922	Hard gray lime, coarse
935	Hard lime, gray and black
945	Gray lime, hard, coarse
960	Gray lime, little shale
964	Hard gray lime, brown-gray
978	Hard lime, dark gray
1,025	Brown limestone and brown shale
1,050	Gray limestone
1,053	Hard shell, lime—gyp and quartzite
1,058	Hard gray lime
1,107	Black limestone and some shale
1,117	Gray lime
1,120	Gray sandy lime, salt and gyp
1,176	Light and dark gray limestone
1,186	Gray and white lime, very coarse
1,195	Light gray lime, hard and fine
1,198	Light gray lime, very rank gas
1,205	Light gray lime, hard and fine
1,213	Dark brownish lime
1,287	Dark gray shale and limestone
1,311	Brown shale and limestone

LOG NO. 2—*Continued*

Total Depth in Feet through Each Formation	Formation
	Blue or black rock, very hard—smells and tastes like tar
1,318	Hard black lime—few white streaks
1,321	Very sticky blue shale
1,360	Dark gray limestone and light gray shale
1,372	Light blue shale
1,380	Gray lime
1,389	White formation (talc, chalk, or gyp)
1,397	Light blue gray shale
1,408	Gray lime, showing gas
1,425	Brown lime
1,432	Brown shale—very dark
1,451	Black shale—very cavy
1,452	Shell—very hard
1,455	Shale and sand
1,466	Black shale.................
1,475	Gray shale—soft, slightly sandy
1,482	Gray lime, coarse—some crystalline rock like soapstone
1,496	Gray lime
1,498	Gray shale, sticky
1,503	Gray lime, showing salt
1,545	Salt
1,563	Salt, lime and shale
1,565	Gray lime
1,635	Brown shale
1,655	Lime
1,833	Salt
1,835	Lime shell
1,865	Gray shale
1,990	Salt
2,028	Lime and shale in streaks
2,028	Oil and gas in lime—rig burned December 8, 1925
2,025	Corrected measurement
2,027	Gypsum and iron
2,041	Gray sandy lime—very fine grained
2,110	?
2,145	Salt
2,147	Hard lime shell
2,188	Salt
2,189	Hard lime shell
2,193	Salt and gypsum
2,194	Lime
2,253	Salt—very fine grained
2,255	Hard lime shell
2,263	Salt—small breaks blue shale and gypsum
2,265	Lime shell
2,293	Salt—little shale and gypsum
2,296	Black shale
2,342	Salt—little shale, gypsum, and lime
2,345	Hard shell
2,375	Salt—very muddy
2,378	Black shale—cavy
2,380	Salt—soft, muddy
2,409	Salt—shale and gypsum
2,412	Black shale—soft, cavy—streaked with gypsum
2,415	Salt, very soft, muddy—some black shale
2,455	Salt—considerable gypsum, and pink crystalline formation like alum
2,508	Salt—fine white
2,511	Hard shell
2,582	Salt—fine white, some gypsum
2,584	Black shale—cavy
2,604	Gray shale
2,726	Salt—fine white
2,727	Hard shell
2,729	shale and Salt
2,750	Salt—with small gray shale breaks
2,753	Hard lime shell
2,800	Salt, fine and white
2,815	Salt, showing little gypsum
2,816	Hard shell
2,820	Gray porous lime

LOG NO. 2—*Continued*

Total Depth in Feet through Each Formation	Formation	Total Depth in Feet through Each Formation	Formation
2,830	Lime and black shale	3,422	Salt
2,852	Shale—dark gray, muddy, and sticky	3,457	Black shale
2,857	Very hard shell	3,514	Brown sandy shale
2,905	Salt	3,623	Salt
2,970	Salt—fine, some gypsum	3,628	Conglomerate
2,972	Hard shell	3,633	Black sandy shale showing oil and gas
2,995	Fine white salt	3,650	Black shale, more oil and gas
3,007	Salt and gypsum—very sticky and cavy	3,676	Gypsum
3,008	Lime shell	3,682	Salt
3,027	Black shale—soft, cavy	3,688	Gray sandy shale
3,037	Gray shale	3,855	Salt
3,050	Salt, gray medium coarse	3,860	Coarse gray sand
3,195	Salt—little gypsum	3,890	Mixture sand, salt, and shale
3,252	Salt—fine white	4,057	Salt
3,345	Black shale	4,066	Gypsum
3,383	Salt	4,075	Salt and anhydrite
3,385	Hard lime shell	4,090	Black shale
3,389	Gray sandy shale	4,100	Gypsum and gray shale

NATIVE ASPHALTS IN OREGON[1]

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ABSTRACT

The native asphalts in Oregon have never been thoroughly described, their character determined, or their significance discussed. This paper presents a complete list of all known occurrences, some of recent discovery, and tenders for the first time analyses and determinations of their character. They are found to be mixtures of uintahite, manjak, and wurtzilite, or pure uintahites and grahamites. These native asphalts have been derived probably from deep-seated Cretaceous rocks, which once possessed reservoirs of petroleum. The petroleum was brought to the surface by dynamic movements at the close of the Eocene or in the early Oligocene period. Their method of emplacement shows no influence of thermal metamorphism. Some of the Oregon occurrences are similar to those found in other localities which have since developed into important oil fields. Other Oregon occurrences are unique, and neither in Oregon nor elsewhere have they heretofore been described. The whole discussion has an important bearing on the possibilities of petroleum in Oregon.

OCCURRENCE

Native asphalts are known in Coos, Clatsop, Lane, Tillamook, Polk, Wheeler, and Crook counties, Oregon.

CLATSOP, TILLAMOOK, POLK COUNTIES

Washburne found a black shiny hydrocarbon in the vesicles of a basalt on Youngs River near the old Wagon bridge. On the opposite shores of Columbia River in the southwestern part of Ilwaco County, Washington; a substance resembling ozokerite, in a vug-like cavity lined with quartz, occurs in a basalt flow.

In eastern Tillamook County, six miles southwest of Skukum Lake, at the head of a small creek entering Wilson River from the south, a vein about $\frac{1}{2}$ inch thick, black, and about as hard as asphalt, was found by I. H. Collier.

In Polk County, near Eola, $4\frac{1}{2}$ miles west of Salem, veinlets of a brilliant black, solid, brittle hydrocarbon $\frac{1}{8}$ to $\frac{1}{4}$ inch thick have been found.

COOS COUNTY

"Pitch coal" has long been known in the Coos Bay coal field and was first described by Diller. In the same report W. C. Day and S. F. Peckham discuss its composition and origin. Near Coos Bay veins of "pitch coal" occur in the old Ferry coal mine near Riverton, in the old Newport coal mine at Libby and at several other localities. These occurrences deserve further consideration in view of the additional data herein presented.

Character of material.—The "pitch coal" (Table I, analysis 7) has a jet-black color when fresh which weathers to a dark brown with lighter brown streaks. It separates with a hackly fracture into prismatic pieces $\frac{1}{2}$ inch in thickness, which

[1] Manuscript received by the editor, December 5, 1926.

break further with a conchoidal fracture. Some pieces are easily ignited with a match; others simply melt and yield a heavy smoky flame. The melted material flows easily, sticks to cold paper when very hot, and may be drawn out into long threads. Rubbed, it produces positive electricity. It decomposes at 170° C. and gives off at first a brownish gas and later a greenish, very inflammable gas, which

TABLE I

ANALYSES OF OREGON ASPHALTS

	1 Grahamite *	2 Grahamite †	3 Manjak ‡	4 Uintahite §	5 Uintahite ‖	6 Wurtzilite ¶	7 "Pitch Coal" **
Color	Jet black	Jet black	Jet black	Black	Black	Black	Jet black to brown
Luster	Brilliant	Brilliant to dull	Brilliant	Brilliant	Brilliant	Brilliant	Brilliant to dark
Streak	Brown	Brown	Brown	Brown	Brown	Brown	Brown
Fracture	Conchoidal to hackly	Conchoidal to hackly	Conchoidal to hackly	Conchoidal	Conchoidal	Conchoidal to hackly sectile	Conchoidal to hackly
Specific gravity	1.14–1.145	1.07–1.08	1.08–1.175	1.01–1.171	1.07–1.08	0.90–1.07	1.11–1.28
Hardness	2	2.5	2	2–2.5	2	2–3	2.5
Electrical charge	Positive	Positive	...	Positive	Positive	Negative	Negative
Softening point C°	175–315	330	139–162	125	275	...	165
Fusion point C°	Initial 200, cokes 175	340	145–220	Initial 200 to 205	290	Initial 315	170–180
Per cent volatile at 165°C.	0–1	0–1	...	1	0	0–1	0.5
Per cent fixed carbon	30–56.4	23	24.7–31.7	10–35	5.1	...	12 at 210° C.
Per cent ash	30–56.4	Spongy coke	4.4–13.9	...	0	2–25	8.3
Per cent soluble in CS_2	45–100	75	93.4–98.3	98–100	98–99	5–20	100
Per cent soluble in CCl_4	20–99	53	...	99.6–100	100	0	100
Per cent carbenes	0.80	22	...	0–2.0	1–2	Trace–2	0
Per cent soluble in benzine	Partly	25	84.3–95.3	98–100	99	Very ?	100
Per cent soluble in petroleum ether; boiling point 40–60; sp. gr. .633	Trace–50	0	22.2–36.4	20.60	30	Trace–10	10.5
Per cent soluble in ethyl alcohol	0	0	...	0–54.6	Slightly	...	0
Per cent soluble in chloroform	90–100	70.5	...	Partially	100	...	100
Per cent asphaltenes	...	70.5	...	...	70	...	89.5
With H_2SO_4	Decomposes	Decomposes	...	...	Reacts slightly	...	Reacts strongly
With NaOH	0	0	...	...	0	...	Reacts slightly

* According to Kirkpatrick, Redwood, Danby, Abraham, Dana, Smith, Scott, Eldridge, and Hodge.

† Sample from Huntley Ranch near Clarno, Oregon. Analysis by Hodge.

‡ According to Kirkpatrick, Redwood, Danby, Abraham, Eldridge, and Hodge.

§ According to Kirkpatrick, Smith, Scott, Redwood, Danby, Abraham, Eldridge, and Hodge.

‖ Sample from vicinity of Clarno, Oregon. Analysis by Hodge.

¶ According to Eldridge, Danby, Scott, Smith, Kirkpatrick, and Hodge.

** Sample from Newport coal mine, Coos Bay, Oregon. Analysis by Hodge.

condenses on the side of the crucible and finally volatilizes. The gas continues to pour off for a long time without bubbling or foaming, especially at 180° C. when completely fluid. All gas is given off at 210° C., affording a slight ammoniacal odor toward the close of distillation. A gray paper ash is left at white heat and a small silver-white graphite deposit is attached to the bottom of the crucible.

Genesis.—The writer agrees with Danby that overheating produces a large percentage of carbenes.[1] The absence of carbenes, therefore, suggests that the met-

[1] The term "carbene" is employed for those constituents soluble in carbon bisulphide but not soluble in carbon tetrachloride. Carbenes are especially common in grahamite, native asphalts, and asphaltites.

amorphism of this material has not been due to heat. The very high specific gravity points to considerable metamorphic change. Increase in specific gravity may be, and usually is, associated with an increase in ash and decrease in petrolenes.[1] Ash, not including mineral impurities, is due to oxidized hydrocarbons. The moderate ash and the low fusibility indicate little or no oxidation; hence, no surface exposure. The field occurrence also denies the possibility of exposure to the surface. The specific gravity must, therefore, be due to a molecular condensation of original compounds. The petrolenes are fairly plentiful in this material and may have been present at one time in greater amounts. Inspissation of petrolenes accompanied by condensation would result in an increased specific gravity. This must be so since the asphaltenes[2] constitute the bulk of the sample. The low fusibility indicates that the asphaltenes are to a large extent in their original state. If the asphaltenes have not been altered, then the metamorphic change must have affected only the petrolenes. The source of the petrolenes was probably from the grahamite part of the sample.

The chemical evidence points to a substance which is a mixture of grahamite, wurtzilite, and manjak, which has not been oxidized by exposure, affected or produced by heat, but has undergone a molecular condensation of its petrolenes, leaving the asphaltenes intact. It is clearly a petroleum-derived material. The absence of carbenes and the field occurrence prove that the "pitch coal" has not been derived by the distillation of coal beds. No igneous rocks occur within several miles of the veins.

Small veins of this material cut through more or less crushed and crumpled coal beds. The veins cut both the upper and lower coal horizons and give every evidence of later emplacement than the coal. The veins are closely jointed and very brittle, indicating a thorough chemical change to a solid bitumen and suggesting movements subsequent to solidification. The coals are Eocene and the veins are post-Eocene. The fissures through which the petroleum escaped were perhaps formed by the crustal movements along the coast which took place at the close of the Eocene.

The veins of this natural asphalt can be traced downward and it is possible that they originated in a bed of brackish and marine fossils just below them in the unexposed Cretaceous. This Cretaceous formation as traced northward contains more and more marine strata and fewer terrigenous sediments and it is possible that the marine beds of the Cretaceous have been the source of this natural asphalt.

LANE COUNTY

The occurrence in Lane County on the ranch of A. B. Johnson, on the North Fork of Siuslaw River about six miles northeast of Florence, was first described by Washburne. The following is an abstract of Washburne's statement:

[1] Petrolenes are the volatile hydrocarbons of petroleum and are the part soluble in petroleum ether, ethyl ether, or acetone.

[2] Asphaltenes (Danby) or malthenes (Richardson) are those parts dissolved by boiling in turpentine or chloroform.

The oil is found in cavities and narrow joints, near the lower margin of an inclined dike in sandstone and shale. A sample examined by D. T. Day shows 1 per cent of an oily hydrocarbon soluble in gasoline, and 0.4 per cent of typical asphalt soluble in both ether and benzol.

The two types of hydrocarbon were distinct in character and entered in two different periods. The former is dense, black, solid but not brittle, breaks in irregular curved fractures, readily melts on a stove, and lighted burns with a smoky yellow flame. It coats the cavities in the basalt to a thickness of 1 to 4 mm. and in places fills them completely. Within the shell of black asphalt there is commonly a layer of calcite and zeolite which may, in some specimens, fill the cavity. The liquid phase is yellowish-brown, viscous, almost transparent in small drops. It reached its present resting place in the basalt cavities some time after the infiltration of the oil from which the solid black residue was deposited and after the deposition of the zeolite and calcite. The liquid oil in some way managed to penetrate the coatings of asphaltum and minerals to the center of the cavities, where it fills the space previously occupied by water. It is a comparatively recent infiltration, accomplished after erosion had removed enough of the overlying material to bring the rock represented by the samples close enough to the surface. The solid black asphaltum has been derived from the first oil, by the loss of its liquid solvents. The oil entered the rock from the underlying sedimentary rocks a long time after the basaltic intrusion.

Washburne further states that a black pigment, probably hydrocarbon, which disappeared when strongly heated, was found in the cleavages of calcite crystals in a veinlet cutting a basalt dike on the Southern Pacific Railway a mile east of Springfield Junction.

WHEELER COUNTY (GRAHAMITE)

Grahamite and uintahite have been found in Wheeler County. One occurrence has been described by Collier as follows:

A body of asphalt said to have contained several bushels occurs in Sec. 31, T. 7 S., R. 20 E., a short distance above the mouth of Cove Creek. The asphalt was found on a bluff of tuff along the south side of Pine Creek, about 100 yards southwest of the barn on the Huntley Ranch. The tuff for some distance away from the opening contained a great many rounded grains of the material ranging in size from a pinhead to a pea. Other fragments were found along the foot of the bluff, where they had been worked out by the squirrels.

During the summer of 1926 the writer visited a new locality discovered by Mr. T. H. McGreer on the north side of Dry Creek in the northeast corner of Sec. 20, T. 8 S., R. 19 E. This material occurs in veinlets ranging in thickness from 0.1 inch to 0.5 inch. One impure lenticular vein is 2 feet long and 0.5 inch thick. The clay shales adjacent to the veins are impregnated with asphaltite. The material contained so much clay and sand that quantitative tests were not made. Qualitative tests, however, proved this material to be identical with that on the Huntley Ranch.

Character of material.—The material on the Huntley Ranch (Table I, analysis 2) is an easily fractured sealing wax-like substance. Where it has lain exposed a long time it shows only a slightly dull luster due to fine pitting on the surface. Frag-

ments as small as 0.01 inch thick are brittle between the teeth. Smaller fragments are slightly malleable. The streak on paper is a rich brown. It may be electrically excited by friction sufficiently to pick up a piece of paper. It melts in a candle flame, swells, bubbles, and spurts out smoky flames of gas, much like sealing wax; and like this material takes an impression when warm. It will not, when warm, adhere to cold paper. The gases burn briefly in still air. At 330° C. it swells and gives off strong fumes of a very inflammable gas with a faint petroleum odor. This gas is gray with brown streaks. The brownish gas ceases while gray fumes still rise, and leaves a brown volatile stain on the sides of the crucible. All its properties are like those of grahamite except specific gravity. Redmond gives 1.14 as the lowest specific gravity for grahamite and most authorities give specific gravities up to 1.20. The low specific gravity of this sample is not in harmony with the fairly large amount of fixed carbon. The absence of light petrolenes proves that they are not responsible for the low density. Perhaps the low specific gravity is due to the presence of wurtzilite which responds next to grahamite in the different tests.

Genesis.—The 22 per cent of carbenes is only one-fourth of that which some grahamites carry, and betokens some, but not a great, thermal metamorphism. The percentage of fixed carbon plus ash is at the lowest limit reached by grahamites; hence, the hydrocarbons have undergone but little change. Pyrobitumens and asphaltic pyrobitumens may be looked upon as the end products of changes in hydrocarbons to fixed carbons; they are insoluble in carbon bisulphide and are evidently absent in this material. This evidence of no alteration proves that the zero petrolenes cannot be accounted for by volatilization. Inspissation, oxidation, or molecular condensation of petrolenes would result either in increased density or fixed carbons, or both. It must be concluded that this material is composed almost entirely of asphaltenes.

If the material is now and has always been asphalteneous and if no change has taken place which would increase the specific gravity, what then gives the material its high melting point?

Richardson states that when crude petroleum, which contains a large percentage of hydrogen and therefore simple hydrocarbons, is subjected to heat and pressure under favorable conditions, a large volume of gaseous hydrogen is eliminated, resulting in the conversion of the hydrocarbons into compounds more complex both chemically and physically. Colloidal clay accelerates the process by acting as a catalyzer. The petroleum is converted into asphalt by emulsification with clay, sand, and water by means of natural gas at high pressure. Richardson says grahamite is due to a condensation of paraffin oils and so differs from uintahite and manjak, which are formed by unsaturated hydrocarbons.

In this sample the chief change must have been accomplished by the catalytic action of the colloidal clay during the long time involved in slow seepage upward by the emulsified petroleum from the deep-seated reservoirs.

The derivation of this grahamite without the influence of heat or pressure is of great significance since it occurs in the volcanic Clarno formation in intimate asso-

ciation with dikes, sills, and flows. The occurrence in veins and the evidence cited indicates an origin at a time later than the volcanic Eocene. Probably at the close of the Eocene or in early Oligocene time, crustal movements fractured the rocks and permitted the petroleum to work its way slowly to the surface. This time of origin corresponds with that assigned to the "pitch coals" at Coos Bay.

WHEELER COUNTY (UINTAHITE)

Uintahite occurs closely associated with the grahamites of Wheeler County. The uintahite occupies veins and geodes in one of the Clarno rim rocks at the head of a draw in the southeast corner of Sec. 26, T. 7 S., R. 19 E. These beautiful geodes and inflammable bitumen have been known to the ranchers near Clarno for a long time. Collier states:

> The asphaltum occurs in the geodes in small grains. One large geode approximately one foot in diameter, nearly spherical, and smooth on the outside was found, which contained a quart or more of asphaltum. Many fragments of similar geodes are scattered over the surface, but few, if any, perfect ones remain in unbroken condition. No asphaltum was found either in the tuff or the andesite country rock.

Character of material.—The physical description of this material is identical with that of the grahamite (Table I, analysis 5). The melted cold material retains its black luster. It bubbles at 275° C., produces an odorless, grayish gas with streaks of brown, and finally continues to give off gas long after bubbling ceases, which at 280° C. forms a brown oily stain on the crucible. The ash is white and 0.1 per cent of a metallic silver-white graphite residue is attached to the bottom of the crucible. It resembles the soft Utah uintahite in its low specific gravity and in the percentage of coke. It is unlike the hard uintahite of Utah and the Oklahoma uintahite in specific gravity, and unlike all of the uintahites except the jet in its high melting point. In respect to melting point it approaches grahamite. In all other respects this material closely resembles uintahite as described by several authorities.

Genesis.—Because only 10 per cent of carbenes are present above the minimum possible, but little thermal alteration has taken place. If petrolenes were present, they did not volatilize at the surface. Oxidation would lead to high ash, and inspissation accompanied by molecular condensation would give high fixed carbon or high density. These facts added to the ratio of 30 per cent petrolenes to 70 per cent asphaltenes show that the petrolenes are intact. The high melting point is evidence of a substantial change in the asphaltenes. The melting point is not due to pyrobitumen or asphaltic pyrobitumen, as is shown by solubility in carbon bisulphide. Richardson says that uintahite is formed by unsaturated hydrocarbons and is free from paraffin oils. The melting point, therefore, has been due to alteration of the unsaturated compounds brought about by catalysis. The intimate association of the uintahite with amorphous quartz suggests that it passed through colloidal solutions of silica as it came toward the surface.

The time of its origin was late Eocene or early Oligocene, as is shown by its field occurrence. The lower part of the Clarno formation is separated from the

upper part by an olivine basalt which is about 100 feet thick. This basalt, where nearly horizontal, forms a rim rock with a prominent bench above it. It forms striking hogbacks where standing at an angle and close to John Day River. Geodes occur at the bottom of the rim rock and close to the upper contact with thick tuff beds. These geodes have diameters from 7 cm. to 30 cm. They occur as clearly defined units which weather out from the basalt as nondecomposing spheroids. They break free from the decomposed basalt, retaining smooth exteriors or exteriors which show the imprint of basaltic vesicles or of minerals which formed in the pre-geodal cavities. Thus a few geodes show molds of pre-existing fibrous aragonite or calcite. These molds in chalcedony look like fossil wood, except for the intersection and divergence of the structure. All geodes have the same mineral composition. One type contains uintahite; another is an empty cavity. Some uintahite-bearing geodes at the coalescence of several gash veins have good spheroidal form.

All of the geodes have chalcedony walls. In some specimens this chalcedony forms a simple wall 1–5 mm. thick around the entire geode, its color grading from white on the outside to pale blue on the inside. In a few specimens the chalcedony forms an onyx layer 1 cm. thick at the base of the geode. In others, nodules of dolomite crystals with rosette surfaces occur within the chalcedony. Implanted on the chalcedony are transparent subhedral quartz crystals, ranging in size from 2×3 cm. to 2×6 mm. The quartz crystals are of the common habit with striated prismatic faces terminated by two sets of rhombohedral faces. A little calcite cement lies between the quartz crystals. In a few geodes, large 1- to 3-cm. tabular rhombs of calcite lie on the quartz crystals and nearly fill the geode.

Uintahite, where calcite is the central filling, forms thin layers between the calcite rhombs. In the typical specimen calcite is not present, and the uintahite occurs as small 5- to 10-mm. spherical masses molded on the ends of quartz crystals. In most specimens, the uintahite nodules do not entirely fill the open space, are themselves bounded by smooth walls, and are implanted on the roof or walls of the geode.

In occurrences due to the intersection of several gash veins the quartz walls continue at the place of intersection and may form parallel spaces. Here the uintahite may form large masses several centimeters in diameter within these cavities.

It may be concluded that calcium carbonate was the first substance to form in the large vesicular cavities or gash fractures in the basalts. Later, comparatively cold waters, at least waters not genetically associated with the origin of the volcanic rocks, arose from the depths, bearing in colloidal solution silica and petroleum emulsion. The petroleum was probably derived primarily from Cretaceous, although it may have been obtained from Triassic, or Jurassic, marine rocks. The silica may have had its origin from deep-seated plutonic sources. The initiating cause of the ascent was diastrophic movement at the close of Eocene, or in early Oligocene, time.

As these colloidal solutions of silica and petroleum emulsion moved toward the surface, changes were wrought in the petroleum induced only in a minor degree by

heat or pressure. The essential change was one performed by association of the petroleum in a colloidal solution with silica, a catalytic change, and a change accomplished at the time of the escape of the altered petroleum from this solution.

The silica was first precipitated as a jel on the walls of the cavity. During the hardening of the jel, the asphaltite, as yet unhardened, was squeezed out. The uintahite was formed like stalactites on the geode walls at those places where forced out of the crystallizing silica. It did not form a liquid which afterward solidified, because it is found on the roofs and walls of the cavities and not on their floors.

The waters of the colloidal solution dissolved the original calcite and recrystallized it on the inner walls of the geode. During this event the asphaltite was again squeezed to the center of the cavity. On the walls of the central cavity the uintahite slowly formed and hardened. The hardening process has continued down to the present time.

CROOK COUNTY

Veins and geodes similar to those near Clarno, Oregon, occur 1½ mile west of the O. C. Gray ranch on the Post-Paulina highway 10 miles east of Post. The material is scattered in a rhyolite dike and a purplish-gray rhyolite tuff which is

TABLE II

Sample*	Per Cent Soluble in CS_2	Per Cent Soluble in CCl_4	Per Cent Carbenes
2	75.0	53.0	22.0
5	99.0	100.0	0.5
7	100.0	100.0	0.0

* Figures refer to samples cited in Table I.

overlain by a massive basalt. The main deposit lies below the basalt but a smaller deposit is to be found in the basalt about 200 feet higher on the hill. A well was drilled about 500 feet deep near the lower deposit. A lake some distance away is reported to show kernels of asphaltite similar to the Post material, along its shore at low-water stages. The uintahite occurs in single spheroids about 7 mm. in diameter, or as several linked together. Dolomitic rosettes are more common near the borders of the geodes and veins than in the Clarno material.

With these data, the common origin of the asphaltites may now be considered.

ORIGIN OF OREGON ASPHALTITES

The carbenes of all samples show but little thermal metamorphism or genesis. The absence of adjacent igneous bodies and of carbenes prove that the "pitch coal" has not been formed by the distillation of coal beds. In eastern Oregon where the asphaltites are intimately associated with igneous bodies, the minimum percentage of carbenes is especially significant. Only the Huntley sample shows any heat influence. Volcanic genesis should find its best support from asphaltites formed in the volcanic Clarno formation. The post-volcanic emplacement and low carbenes, however, are evidence against a volcanic origin (Table II).

According to these figures, the Coos Bay product now has the least petrolenes and those of central Oregon have the larger quantity. Since the volatile petrolenes have not escaped through the agency of heat these figures may be an expression of time or exposure. The chemical evidence proves that petrolenes of the Coos Bay material have not been lost by surface exposure. They disappeared by alteration while under considerable cover; in fact, today they are found only in mine workings. The grahamite sample never had petrolenes and those of the uintahite remain unaltered. All three materials, therefore, are products formed well below the surface and exposed now by erosion.

Oxidation could take place below the surface by contact with meteoric waters. All samples, however, either by exceptionally low ash or density, show this not to be true (Table III).

Richardson states that asphalts contain 20 per cent plus of saturated hydrocarbons, and that uintahite and grahamite contain only a small amount. The high asphaltene content of the Coos Bay material and high density are thus explained. In the uintahite and grahamite a similar molecular change has taken place, but expressed by a high melting point.

TABLE III

Sample*	Per Cent Soluble in Petroleum Ether	Per Cent Soluble in Chloroform	Per Cent Asphaltenes	Per Cent Ash
2	0.0	70.5	70.5	23.0
5	30.0	100.0	70.0	5.1
7	10.5	100.0	89.5	8.3

* Figures refer to samples cited in Table I.

As a general rule, a bitumen is harder in proportion as it contains more asphaltene to petrolene, until finally some of the very hard types are reached in which but little trace of the latter is found. The literature suggests that this is due to volatilization of the petrolenes. There is no reason, however, why the petrolenes could not undergo molecular condensation resulting in a higher density or a higher melting point. Such appears to have been the history of the Oregon asphaltites.

But even so, the petrolenes were never present in large percentages. Asphaltenes are more susceptible to molecular changes and hence to the production of hard asphaltites. The molecular changes must have been catalytic, produced in petroleum emulsions as they worked their way upward through colloidal clays or in association with colloidal silica.

A discussion as to the source of these asphaltites and data bearing on prospective petroleum evidence will be left to a subsequent paper. Suffice it to say that the asphaltites along the Oregon coast may have been derived from patches of Tertiary marine rocks found from Coos Bay northward. Evidence now at hand points to the existence of unexposed marine Cretaceous along the entire Oregon coast.

In eastern Oregon the Tertiary is continental and largely volcanic. Since the

evidence points to a non-volcanic origin, the asphaltites must have come from deeper strata. The known distribution corresponds closely to the supposed distribution of Cretaceous rocks. Beneath the Cretaceous, however, marine Triassic and Jurassic rocks occur in which asphaltum-coated fossils are found near Post.

It is the writer's opinion that the asphaltites were probably brought up from the Cretaceous rocks during crustal movements at the close of the Eocene or at the beginning of Oligocene time. The deep burial of the Cretaceous rocks and the fact that exploratory drilling has never penetrated them makes it impossible to state that petroleum occurs in the Cretaceous rocks of Oregon at the present time.

SIMILAR OCCURRENCES

Occurrences of solid asphaltites similar to those of Oregon are not common. Kirkpatrick states:

> Uintahite is of uniform composition and properties, being one of the purest known hydrocarbons, found only in one locality, the Utah Basin, along the Utah-Colorado border. Here most of the veins occur in the vicinity of Dragon and Watson, Utah.

Veins of asphaltites in non-volcanic sedimentary rocks are the most common. These occur in regions where, since their earlier discovery, commercial deposits of petroleum have been found. Veins similar to those at Coos Bay have been elaborately described for the United States by Eldridge and are common in other parts of the world.

Veins of solid asphaltite in crystalline rocks are very uncommon. Thus Eldridge and others mention bituminous schist in Canada, in Kentucky, and Virginia (anthroxolite). Eldridge states that gilsonite occurs in veins in the Middle Park formation of Colorado where

> the condition in which the gilsonite found its way into the veins seems to have been that of a plastic mass, coming from below under pressure, and, although of high viscosity, sufficiently fluid to be pressed between the grains constituting the wall rocks.

Kimball describes a vein of grahamite at the Crista mine, in Huasteca, Vera Cruz, Mexico. Emmons says that asphaltites are found associated with mercury ores in California. Dana in the *System of Mineralogy* mentions their occurrence in gneiss and mica schist in the Caucasus.

Percival reports solid bitumens filling thin seams and veins in eruptive rocks in the valley of Connecticut River. In the eastern part of the state of New York, in the region of eruptive and metamorphic rocks, veins occur similar to those reported from Connecticut. Russell describes veins in the trap of New Jersey, filled with a bituminous mineral. Danby states that south of the two ranges of hills around Bentheim, Germany, a vein of solid bitumen averaging from 20 to 30 inches thick is found in the middle of an argillaceous schist. He states that veins of more or less importance occur in the "peperites" of the Auvergne, France. The "peperites" is a local name for a soft, incoherent yellow-gray tuff, containing broken crystals of feldspar, leucite, biotite, and augite, and rock fragments embedded in a

finely granular base. None of these occurrences is exactly like those in the Clarno formation of Oregon, except perhaps the last.

Writers give the impression that deposits of *solid bitumens occurring in cavities or vesicles* of igneous rocks, presumably without vein connections, are common. Actual citations of exact occurrences or descriptions of these occurrences are meager, however. Thompson states that asphaltite in vesicles is due to condensation of volatile petroleum, evaporated by intrusion of igneous rock. Danby reports pure bitumen, uncontaminated by foreign matter, in cavities of the ophites of the *landes* of France and the syenites of Cuba. These occurrences appear to be similar to those in Clatsop and Lane counties of Oregon.

The uintahite in the geodes in Wheeler and Crook counties of Oregon appear to be new types of occurrences. Only two known occurrences have been described, resembling in any way the Oregon types. W. Wright found a tarry substance with carbon dioxide in cavities of a pegmatite in Branchville, Connecticut. Beck says that some of the cavities of the New York limestones and the crystals which line them are covered with a substance black and shining, with the fracture and appearance of anthracite.

The geodal occurrence is interesting, therefore, because of its exceptional occurrence in a geode associated with primary minerals in volcanic rock. It was not formed through desiccation and alteration of a "seep," but must have had an origin contemporaneous with, and similar to, the associated quartz and calcite.

CONCLUSION

This comparison with other known occurrences and the study of the chemical character and history points to a source from native petroleum derived from some pre-Tertiary formation at the close of the Eocene or beginning of the Oligocene, and brought to the surface by dynamic agencies. As far as the writer is aware, the occurrence of uintahite, or any asphaltite, in geodes has not been hitherto described. The discovery of uintahite in Oregon affords the second known occurrence of this rare and pure asphaltite. Now that attention has been called to the character, method of occurrence, and significance, it is confidently expected that asphaltites will be found in many other localities in the unexplored parts of Oregon. The evidence clearly proves that marine beds in Oregon once contained petroleum and may yet possess economic deposits of petroleum.

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OUTLINE OF THE GEOLOGY OF SIAM WITH REFERENCE TO PETROLEUM[1]

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ABSTRACT

Weathering and alteration of the rocks are deep. There are three topographic provinces: the drainage basin of MeNam River, the Korat Plateau, and Siamese Malaya.

The Paleozoic rocks of the MeNam basin and Siamese Malaya are metamorphic. In the Korat Plateau of northeastern Siam and locally in northern Siam, there are thick beds of Triassic sandstone, gently folded. In northern Siam and Siamese Malaya there are limited basin deposits of Pleistocene beds. These beds are steeply folded in some places but are not metamorphic. The principal igneous rocks are granite laccoliths; but andesite and other intrusive rocks are present, and there are some small basaltic flows.

In the Paleozoic rocks the structures are closely folded. As a general rule the Triassic beds rarely have dips exceeding 10 or 12 degrees. The Pleistocene beds are in many places much disturbed and dips as great as forty degrees are not uncommon.

Tar seeps in the narrow MeFang Valley in the extreme north occur on the margin of a synclinal basin between Paleozoic metamorphic rocks on the west and Triassic red sandstones and granite on the east. The seeps issue through arkose outwash deposits. There are no known source beds in any of the rocks exposed, and the source of the oil is problematical. Structural conditions are favorable in the Triassic beds in a part of the Korat Plateau; but no source beds are known, and there are no indications of oil in the Triassic. No Tertiary beds are known to be present in Siam.

INTRODUCTION

The climate of Siam is hot and humid and causes intense disintegration and alteration of the rock outcrops. In the greater part of the country there are two seasons: a short rainy season begins in June with occasional rains, and continues with increasing precipitation to a climax of several weeks of almost continuous rainfall in October. At the close of this period, rains cease abruptly; and in general, only occasional rains fall before the beginning of the next rainy season. The climate is, however, hot and humid throughout the dry season; and in many parts, particularly in the mountains, the night dews are so heavy that one awakes to hear the drip of the dew on the leaves like the patter of rainfall. During the rainy season, the low country is almost a lake, and travel away from the railroads is almost impossible.

As in all countries of this type, the alteration of the rocks is very deep, and the rocks are in many cases difficult of identification. The soil is deep, and outcrops are few. Granite is always decomposed to great depths, except in the vicinity of mountain streams. In one railroad cut, complete decomposition has taken place to a depth of more than 50 feet. The cementing material of quartzite becomes re-

[1] Read before the Association at the New York meeting, by W. B. Heroy, November 16, 1926. Published by permission of the Commissioner General of Railways of Siam.

dissolved, and the rare exposures usually suggest sandstone. Slate is completely altered to clay. The most resistant rock is siliceous limestone, altered to marble which stands out in bare jagged pinnacles. Lines of travel follow the low-lying river basins, and the hilly regions in which outcrops may be found are only accessible by trails. Whether one travels by pony, caravan, ox-cart, or boat, the maximum distance which can be covered in a day is only 10 or 15 miles as, on account of the heat, it is impossible to travel during the middle of the day. A side trip into the hills to search for outcrops will consume, therefore, two or three days without any but the most meager data being secured. As the Siamese are an agricultural people, there is practically no life in the hills; and trails are absent in many of the localities proposed for examination. On account of the jungle, distant views of topography are nearly always impossible. Only in a few instances was it possible to see the adjacent hills from the crests, even by climbing trees. One may pass within a relatively short distance of considerable hills without being conscious of their presence.

TOPOGRAPHY

Topographically, Siam falls into three provinces: the central area, consisting of the basin of MeNam River and its tributaries; northeastern Siam, consisting of the Korat Plateau; and a third province, consisting of that part of Siam lying in the Malay Peninsula.

The central basin is similar in many respects to the basin of Mississippi River. Several streams gather in the enclosing mountainous areas and unite to form MeNam River. For a distance of 350 kilometers above its mouth, the river forms an alluvial plain and delta, similar to the alluvial plain and delta of the Mississippi below Cairo. In the vicinity of Bangkok, the capital, the plain is so flat that one seems to see the curvature of the surface by the disappearing trunks of distant palm trees. The enclosing mountains have an elevation generally not in excess of 4,000 feet, and the average elevation is probably not more than 3,000. Exceptional peaks have elevations of more than 8,000 feet. Beyond the plains, the relief is rugged; and the mountains are covered with jungle, with bamboo undergrowth. Above the delta plain of the MeNam, the rivers run through a series of open valleys and narrow steep canyons, which, if submerged, would become a series of lakes connected by narrow straits. These basins vary considerably in size, but they are rarely more than 25 miles long and 10 miles wide. They constitute the only arable land in the central province above the great delta plain of the principal river. Until the last century, these valleys, separated from adjacent basins by stretches of rugged mountains and gorges, constituted separate kingdoms ruled by rival kings living in walled cities, whose principal interest was waging more or less chivalrous war on their neighbors.

Northeastern Siam, also known as the Korat Plateau, is separated from the central basin by a range of forbidding mountains. Soil and topography are in sharp contrast. The soil on the plateau is sandy, and the hills are low and rolling. The surface had been shaped by the meandering of MeKong River and had been re-

duced to a peneplain before the elevation of the surface which resulted in its isolation. Old meanders of the river are distinctly visible from the air, the broad sweeps of the old channels being now cleared and occupied by rice fields. Since the chan-

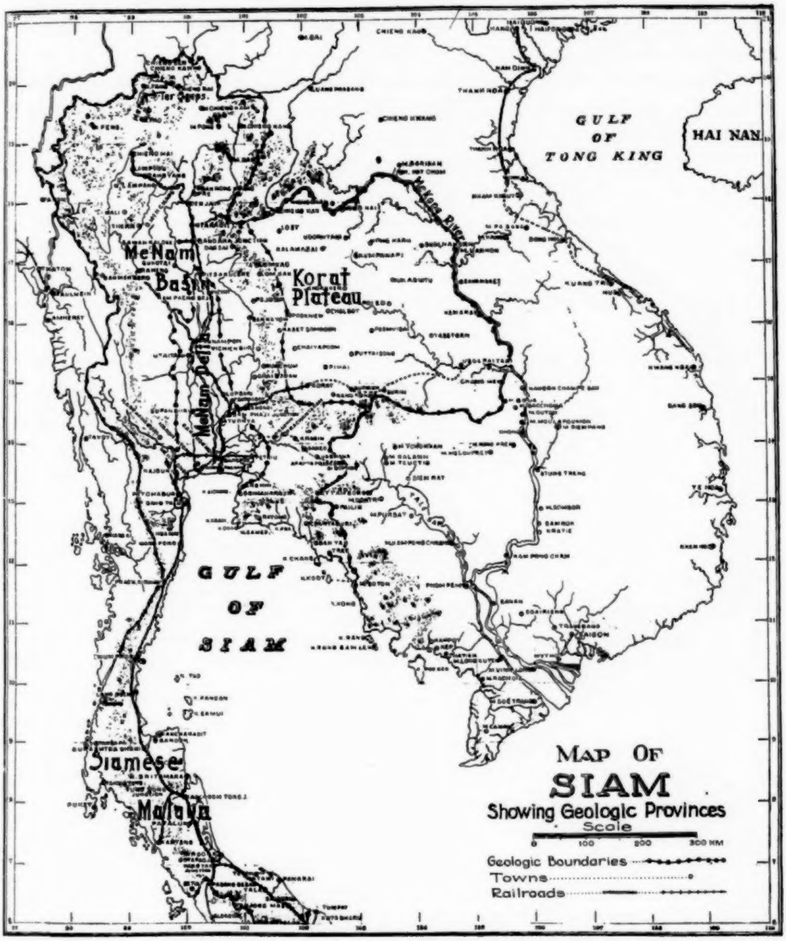

FIG. 1

nel of the MeKong was turned elsewhere, this region has not been materially eroded, but MeKong River has trenched a gorge 200 to 300 feet deep along the eastern margin. During the rainy season, water stands in great lakes in the old meanders, while during the dry season, the region is dry and desiccated. The surface is very

gentle, but a range of structural hills about 1,000 feet high occupies the northeastern margin. The surface rises gently toward the south, where it is bounded by an extraordinary cliff for a distance of nearly 150 miles. Toward the north, since its deflection from the plateau area, MeKong River has not deepened itself very materially, so that the topography of the Korat Plateau merges in this direction into the earlier topography.

Siamese Malaya is an extension of the mountain range separating Burma from Siam. The mountains are not high, and in several places the peninsula is nearly cut through by rivers with divides only a few hundred feet above sea-level. This region receives more rainfall throughout the year than other parts of Siam, and the jungle growth is especially heavy.

Though the Korat Plateau has evidently risen in relatively recent times, the central part of Siam and the Malay Peninsula give evidence of having subsided. In the delta of MeNam River and along the flanks of the Malay Peninsula, limestone peaks and other hills rise abruptly through the alluvial plain. It is evident that they were at one time islands, now joined to the mainland by the accumulation of alluvial deposits. The depth of the Gulf of Siam is almost uniform as far east as Borneo and is only about 300 feet deep. It seems evident that in comparatively recent times, Sumatra, Java, and Borneo were joined to the mainland by alluvial plains. In other words, the axis of the Indo-Chinese Peninsula on MeKong River appears to be rising, while the marginal areas on the west and in the Gulf of Siam and parts of the Malay Peninsula seem to be subsiding.

STRATIGRAPHY

Paleozoic.—Most of the mountain masses in central Siam and the Malay Peninsula are composed of metamorphic Paleozoic rocks. It is especially difficult to make a satisfactory analysis of the stratigraphy because very few fossils occur. This is largely attributable to the disintegrating effect of the climate on the surface rock, although partly because of the extreme metamorphism which has occurred. In the course of nearly two years' search, only about a dozen fossil localities were discovered; less than one-third of these were in the Paleozoic, chiefly Permo-Carboniferous. Many of the limestone pinnacles show the presence of Permo-Carboniferous fossils in section, but on account of the extreme metamorphism and the hardness of the rock, specimens cannot be collected. The only outcrops sufficiently exposed to serve for studying even a generalized section were found in the Malay Peninsula where more than 33,000 feet of Paleozoic sediments were measured. The section is given on page 411.

The upper 1,200 feet of this section may possibly represent strata of early Mesozoic age. Strata with similar characteristics were noticed throughout the mountainous regions of central Siam, but, excepting the highly fossiliferous, light-colored Permo-Carboniferous marbles, it was never possible to identify them with confidence. .

Triassic.—In the Korat Plateau and at several places in northern Siam, de-

posits of reddish sandstone were noticed, not included in the intense folding and metamorphism of the Paleozoic.

The Korat Plateau is entirely underlain by these beds, which have an approximate thickness of 4,000 feet. They consist of sandstones, generally reddish in color, many of them containing quartz pebbles and, in some places, pebbles of obsidian. The lower part, about 3,200 feet thick, contains a large amount of shale and probably beds of salt and gypsum, although no exposures of either occur. The base of this series of beds and its contact with the Paleozoic were never found exposed.

No fossils were found, with the exception of a few pieces of badly petrified wood and small broken fragments of bone. In the lower part, logs and driftwood altered to lignite, and poorly petrified wood in places formed the basis of reported coal deposits. In view of the absence of fossils, the age of these deposits may be considered a little in doubt, but it is continuous with the Triassic of Indo-China, where French geologists have found a few Triassic fossils. In northern Siam, a few Triassic fossils were found by the writer in an isolated mass of lithologically similar rocks.

STRATIGRAPHIC SECTION IN MALAY PENINSULA

	Thickness in Feet
Unconformity	
Red and gray sandstone, dark shale, gray shale, and thick limestone beds	1,200
Limestone (Permo-Carboniferous) gray, olive, and drab, generally light-colored, interbedded with siliceous limestone, and with subordinate amounts of calcareous shale	3,000
Sandstone and shale	7,700
Limestone, thin-bedded, sandy and argillaceous, probably interbedded with shale	200
Shale with sandstone beds, and sandy shale, near top and bottom	9,400
Limestone, dark, blackish, possibly Devonian (?)	8,000
Sandstone, interbedded with shale (500 feet thick), underlain by yellow shale, interbedded with thin layers of fine calcareous sandstone	4,000+
Total	35,500

Pleistocene.—In the isolated topographic basins, at several places in northern Siam and in the Malay Peninsula, lignite-bearing rocks of Pleistocene age are found. The relief of such areas is low, and most of the rocks are exposed in the mountains on the margins of the arable basins. The rocks consist of shale, fire-clay, coal, thin sheets of limestone crowded with fresh-water fossils, and subordinate amounts of sand. In spite of the fact that these beds are nearly always steeply inclined, they show a very small degree of metamorphism. The coal beds, some of which are more than 6 feet thick, are impure and have not progressed beyond the stage of lignite. On account of the decomposition and limited exposure, it was never possible to measure a full section; but these beds are at least 200 feet thick and probably much thicker. They are probably lake deposits formed in basins of post-Tertiary disturbances, probably associated with faulting. Similar deposits have been observed by French geologists as far north as Tonkin, where their age is considered Tertiary.

They contain large quantities of fossils in some places, but only a limited number of species.

Quaternary and Recent.—Quaternary and Recent deposits are limited to the flood plain and delta of MeNam River in central Siam and the beach deposits in the Malay Peninsula, some of which are now raised above the sea. These elevated beaches seem to indicate that in relatively recent times there has been oscillation of the land surface of the Malay Peninsula.

Igneous rocks.—Associated with the Paleozoic rocks are immense laccoliths of granite, mentioned in the geologic literature of the Malay Peninsula as "coulisses." At the outcrop they are relatively narrow, being less than 20 kilometers wide; but longitudinally they extend scores of kilometers. The ultimate source of the alluvial tin of the Malay Peninsula is in the pegmatite dikes of these granite masses. They have not been mapped in detail and are best known in the Malay Peninsula, but similar elongated outcrops of granite occur also in northern Siam. Isolated laccoliths on a smaller scale occur on the flanks of the larger masses, but are probably offshoots of the same body.

Decomposition has taken place to such an extent that the character of other intrusive rocks encountered at many places in northern Siam is not determinable. The large majority of outcrops, however, suggest andesite, although more basic intrusions also occur.

In northern Siam and on the Korat Plateau there are relatively recent basaltic lava flows, although none are of any great extent.

STRUCTURE

As has been before mentioned, the folding of the Paleozoic rocks is intense. The axis of folding in northern Siam is, in general, north and south; but in the Malay Peninsula the axis of folding swings slightly to the southeast. The Korat Plateau is interesting in a broad way, in that it occupies the exact center of the huge Indo-Chinese arc of folding which begins in the Himalayan Mountains of northern Burma, swings south and southeast through Sumatra and the Malay Peninsula, and northeast through Borneo into the Philippines to Formosa.

Northeast of Bangkok the trend of the folding, which farther north parallels the Burmese chain, begins to turn southeastward, and, where the rocks pass under the Triassic of the Korat Plateau, the folds trend east. In Indo-China the ranges which are near the coast of Annam parallel the coast, and, passing southward, swing toward the southwest, completing the arc on an offset line of folding concentric with the system. Although the Paleozoic rocks are not exposed in the center of the arc in the Korat Plateau region, the folding which has taken place since the Triassic conforms perfectly with the Paleozoic folding; that is, the dips in the Triassic conform to the general system and form a U-shaped syncline in the center of the plateau. An anticlinal ridge separating the two limbs of the U-shaped syncline is truncated by overlap on the Paleozoic and dies out against the closely folded Paleozoic mountains bounding the plateau on the west side. On the northeast side

of the curving syncline, the Triassic beds rise in several folds, paralleling each other and paralleling the northwesterly Paleozoic folding of the Annam coast. These folds are of a type generally considered as suitable for oil accumulations. The dips range from 3° to 10°, and the anticlines are in part broken into separate domes.

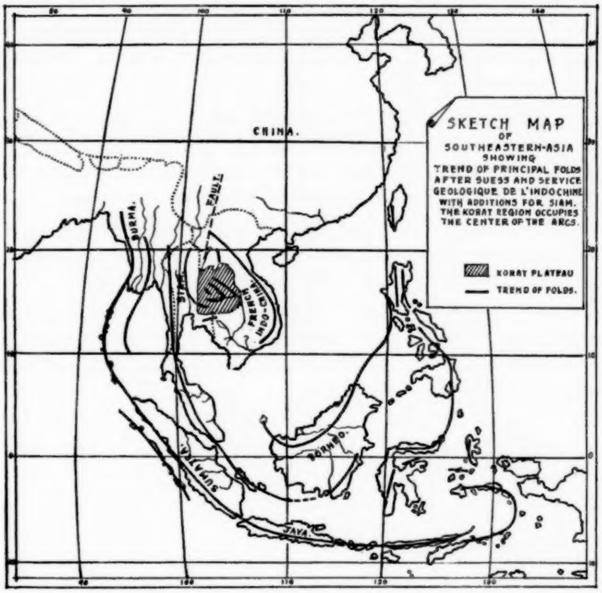

FIG. 2

FAULTS

In view of the difficulties encountered in discovering outcrops, and in identifying strata, it is impossible to speak of faults with any degree of confidence. In a region of such intense folding as occurs in the Paleozoic beds here, it is certain that much faulting is present. The south side of the Korat Plateau is almost certainly bounded by a fault, and some faults probably occur northeast of the Korat Plateau along MeKong River. No faults were noticed in the region of gentle folding in the Korat Plateau itself.

PETROLEUM

The work on which this paper is based was initiated by the Siamese Government because of three tar seeps in the extreme northern part of Siam. At one of these seeps, tar escapes through outwash alluvium in the bed of a small stream, tributary to MeFang River. Two other deposits of sand saturated with tar occur within three kilometers in the beds of similar streams. These three seeps, though not exactly in a straight line, form a very flat triangle. There are no outcrops within three kilometers of the seeps.

About three kilometers to the east is a granite laccolith about 15 kilometers wide, of the coulisse type. On the flank of this mass are beds of reddish sandstone, containing quartz pebbles, similar to the Triassic sandstone of the Korat Plateau, but containing no identifying fossils. These beds rest unconformably on the granite and dip toward the tar seeps at angles uniformly decreasing from 35° to 15°. Only about 200 feet of these beds are exposed, but a uniformly decreasing dip would bring the highest of them about 800 feet below the surface at the locality of the seeps.

Going west from these outcrops across the MeFang Valley, one crosses in succession arkosic outwash from the granite, the narrow alluvial strip of MeFang River, and, west of the river, outwash slopes from the high hills of steeply folded metamorphic Paleozoic rocks of the Burmese divide west of the Valley. These beds dip 35°–40° E. The distance between the westerly-dipping Triassic outcrops overlying the granite and the Paleozoic outcrops which dip to the east is less than 15 kilometers. The distance between the Triassic beds and the tar seeps is only 3 kilometers.

Prior to the author's arrival, the Siamese Government had installed a rotary drill and eventually succeeded in drilling to a depth of 600 feet. The material passed through was chiefly pebbly arkose wash from the granite, but stratified with it were thin beds of clay and some thin beds of lignite.

Briefly, the seeps are found near the eastern margin of a synclinal valley. The rude alignment of the seeps suggests that the tar is escaping either from a fault or from a concealed outcrop of a bed capped by recent alluvium and outwash. The drill explored the surface beds almost to the depth at which the highest exposed Triassic sandstone flanking the granite should have been present at the locality of the seeps. The exposures of the lower Triassic outcrop were good but showed no plausible source beds for oil. It seems, therefore, rather unlikely that the source of the oil is in the Triassic. As the Paleozoic beds have been altered to marble, quartzite, and slate, they seem to be equally unsuited as source beds for the escaping tar. At several places in the valley hot springs occur. One of the hypotheses considered was that the basin itself represents one of the Pleistocene deposits previously described and that intrusions of igneous rock might have come into contact with lignite beds so frequently found in the Pleistocene basin deposits, thus resulting in the distillation of the tar. As the lignite beds are quite hypothetical, however, except in so far as the log of the well showed thin lignite streaks, and as the presence of the Pleistocene itself is purely speculative, the theory is not well substantiated. The actual source of the tar is, therefore, at present indeterminable; and as the possible source beds, whatever they may be, must be distinctly limited on account of the narrowness of the basin, and as the locality is 140 kilometers from the end of the railway in a region without roads and across a high range of mountains, it can not be regarded as very promising.

No other indications of oil were found in Siam. The reported occurrence of oil indications on the west coast of the Malay Peninsula seemed on investigation to have as its basis a prospect shaft for testing the lignite. Gas was observed in this

shaft; and, judging from the descriptions, it was accompanied by peacock iridescence on the water, both of which are, of course, normal accompaniments of coal beds.

Another reported occurrence of oil in northeastern Siam seems to have been founded on the confusion of petroleum with oil drawn from certain trees, by a casual Chinese traveler ignorant of petroleum.

The Paleozoic rocks are so completely metamorphosed that they cannot be expected to serve as a source for oil. The Triassic beds are predominantly sandy, and, except at one locality, do not offer favorable structural conditions. This locality occurs in the range of anticlinal hills on the northeastern margin of the Korat Plateau. In this case, however, the rocks exposed at the surface are the lower sandy part of the Triassic; and, at the most favorable localities, probably less than 1,000 feet of Triassic sandstone beds occur above the unconformity with the Paleozoic. The basal Triassic beds could not be examined; but no source beds are known, although some black shales occur in corresponding beds in Tonkin, two or three hundred miles north. There are no indications, however, such as seeps, that the Triassic beds contain any oil; and the locality could not be regarded as particularly favorable for testing, even if it were in a less remote region.

The oil deposits in Burma, Sumatra, and Java occur in the Tertiary beds. No indications were found that Tertiary beds are present in any part of Siam, and the Indo-Chinese Peninsula seems to have been a positive area and generally rising since the close of the Paleozoic. Prior to the identification of fossils of the Pleistocene basin deposits, it was thought that these deposits might represent inliers of the Tertiary; but the identification of the fossils by the U.S. Geological Survey did not substantiate this hypothesis.

Some black shale was encountered in some of the disturbed Pleistocene beds, and it is not inconceivable that they might furnish a source of oil accumulation. These deposits, however, are confined to limited low-lying arable basins where outcrops are rare and confined to marginal areas. If it were true that the MeFang tar seeps originate in the basin beds, it would still be impossible to work out the structural conditions of the basins without core-drilling, and as the basins are limited in extent, it seems unlikely that much could be expected from such operations.

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THE INTERPRETATION OF THE PHYSIOGRAPHY OF THE LOS ANGELES COASTAL BELT[1]

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ABSTRACT

The Los Angeles coastal belt is traversed by chains of low hills whose anticlinally warped land surfaces correspond to underlying petroliferous structures. The Dominguez surface, named after its exposure on one of the hills, is middle Pleistocene in age. Antecedent streams indicate uplift, but may destroy significant parts of the warped surfaces. Piracy aids the recognition of uplifts. Consequent streams bear a close relationship to underlying structure. Valley-fill, alluvial fans, and sand dunes may cover anticlinal upwarps. Faulting modifies the surface in different ways.

There is a close correspondence between the location of oil fields and the position of topographic highs on the Los Angeles coastal belt. This idea has led to the assumption that all topographic highs indicate the presence of oil, and that the absence of a topographic high is warrant for the rejection of a property. These generalizations are based upon the fact that the coastal region has been deformed so recently that the effects of diastrophism on the surface of the land still persist. A physiographic study of the region indicates that, although there are many places where topographic highs do correspond closely with structures that trap oil, there are highs which have no bearing on the location of oil, and also there are places where no topographic highs occur that may contain oil.

The Los Angeles coastal belt lies between the Santa Monica Mountains on the north, the Santa Ana Mountains on the northeast, the San Joaquin Hills on the southeast, and the Pacific Ocean on the southwest. Near its middle part the shore line is separated from the low land of the coastal belt by the San Pedro Hills, which project as a blunt peninsula into the ocean. The margins of the Santa Ana Mountains and the San Joaquin Hills are characterized by low projecting ridges, which in some regions are extended as lines of anticlinal uplift to, or toward, the fault zone at the base of the Santa Monica Mountains. Of these uplifts the most prominent connects Newport Beach and Beverly Hills. This separates most of the coastal belt from the ocean, and has led to the use of the term "Los Angeles Basin."

One of the elevations on the Newport-Beverly structure line, Dominguez Hill,[3] has a remarkably smooth land surface. This is almost flat on the top of the hill and bends gently downward on all sides, except the southeast, to the contact with

[1] Read before the Association, Pacific section, at the Los Angeles meeting, October 28, 1926. Manuscript received by the editor, January 8, 1927.

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[3] U. S. Geol. Survey, Compton Quadrangle.

the surrounding alluvium. The southeastern end of the hill has been cut away by Los Angeles River. The hill is longer than broad, and its axis trends slightly more easterly and westerly than does the Newport-Beverly line. The structure underly-

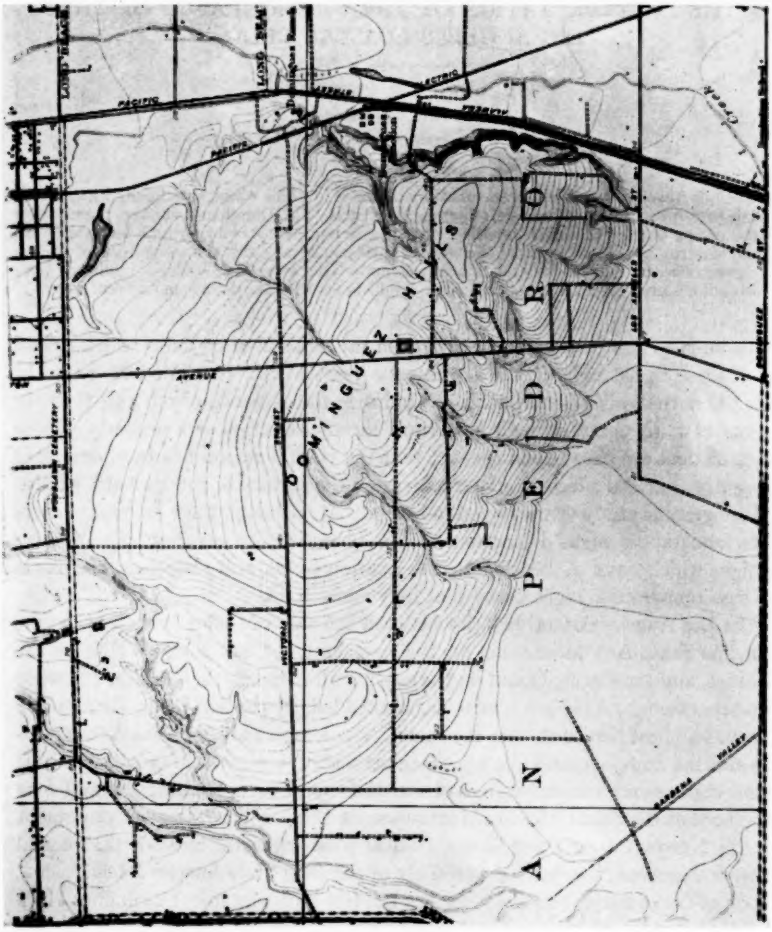

FIG. 1.—Dominguez Hill which shows the form and perfection of the warped Dominguez Surface. Topographic contour interval, 5 feet. From U.S. Geol. Survey. Compton quadrangle.

ing the hill has been proved by the correlation of horizons in many oil wells to be an elongated dome, whose axis trends slightly more easterly and westerly than does that of the hill. The smooth surface of the hill scarcely has been scarred by stream erosion despite the fact that the superficial stratum is a slightly consolidated pebbly

sandstone. As hills of the height and composition of Dominguez Hill, when carved by erosion out of uplifted land masses, are characterized by an irregularity of surface similar to the badlands, and as smooth surfaces are formed on such rocks as plains of degradation or deposition, a hill such as Dominguez Hill, whose form corresponds so closely to that of the proved structure beneath, can only be considered as an anticlinally warped plain. The surface, which is exhibited so beautifully on Dominguez Hill and may be traced almost uninterruptedly to many other parts of the Los Angeles coastal belt, is worthy of a name. May I propose the term "Dominguez surface"?

To the southeast across Los Angeles River the Dominguez surface can be traced to Los Cerritos and the base of Signal Hill. This hill rises above the surface. Its steep sides were modeled in part by the ocean and in part by the streams. Some of the scarp on the southwest side may be ascribed to petty faulting. In a northwesterly direction the surface can be traced by way of Athens and the Baldwin Hills to Beverly Hills and from this locality westerly to Santa Monica. A well-defined topographic unconformity separates the Dominguez surface from surfaces of recent erosion. The topographic unconformity and the characteristics of the surfaces permit their recognition in other parts of the coastal belt. From the city of Santa Monica the surface can be traced into Santa Monica Canyon by means of terraces and benches which are all that remain of a broad valley floor. Similar topographic forms are preserved in other canyons. The valley walls above the terraces and benches rise to another surface, which will be termed locally the "Cahuenga surface."

The Cahuenga surface is exhibited in the Santa Monica Mountains. It is so irregular that it can be differentiated only by a topographic unconformity from the walls of the valleys of Dominguez time. Where the rocks were resistant and the streams were short the Cahuenga surface did not reach maturity, but where the rocks were unconsolidated or the streams were large, broad valleys were formed. The Cahuenga surface truncates rocks of lower Pliocene (Pico) and upper Pliocene (Saugus) age. It is then post-Pliocene in age.

The development of the Cahuenga surface was interrupted by uplift and warping. The low rugged mountains were subjected to deeper erosion by the rejuvenated streams. Diastrophism resulted in the folding of the unconsolidated sediments of the coastal belt. Signal Hill was anticlinally elevated. It is composed of sands and gravels which contain warm-water fossils of Pleistocene age, either interglacial or post-glacial. This epoch of diastrophism must then have been Pleistocene in age. The amount of work accomplished since suggests that it must have been in the early part of Pleistocene time. The rejuvenated streams continued their work without serious interruption until broad valleys were formed in the hard-rock areas, most of the anticlinal uplifts in the soft strata of the coastal belt had been removed, and the depressed areas had been filled with stream deposits. The ocean aided in the reduction of the land surface between Signal Hill and Newport Beach. The composite land surface, in part stream-cut, in part marine, and in

part depositional, is the Dominguez surface. Signal Hill persisted as a remnant of the former surface which the processes of erosion had failed to remove. The age of

FIG. 2.—Signal Hill, showing that this hill rises above the Dominguez Surface. Topographic contour interval, 5 feet. From U.S. Geol. Survey. Clearwater and Long Beach quadrangles.

the Dominguez surface must then be considerably later than that of the sediments on Signal Hill.

After the Dominguez surface had attained its ultimate development, deformation again became the dominant physiographic factor. The mountainous areas were elevated again, and further anticlinal and synclinal warping of the sediments and surfaces took place in the Los Angeles coastal belt. Dominguez Hill and many other similar hills were formed by the warping of the surface. Faulting occurred in many places, notably in the Baldwin Hills and at the base of the Santa Monica Mountains. Signal Hill was raised with the elevation of Los Cerritos and east Long Beach. The processes of deformation, erosion, and deposition were so nicely balanced that streams which previously had flowed from the mountains to the sea maintained their courses across depressions by deposition and across uplifts by erosion. Such streams are antecedent streams. Consequent streams were formed on the newly tilted land surfaces. Streams are now building up the sediments in the depressed areas and are cutting away the uplifted areas. This brief historical résumé is necessary as a background for the consideration of the practical phases of the subject.

On the Los Angeles coastal belt most of the anticlinally warped land surfaces have proved indicative of anticlines which have produced petroleum. Examples are Dominguez Hill, Baldwin Hills, Santa Fe Springs, and Montebello. In some fields the land surface had not been reduced to a plain by Dominguez time; consequently when renewed anticlinal warping occurred, the low hills that remained were carried up on the arched surface. Signal Hill, Coyote Hills, and Montebello are examples of this type. The irregularities of the older surface are difficult to distinguish from those of the modern surfaces. Again the topographic unconformity enables us to differentiate them. The destruction of anticlinally warped land surfaces by streams in recent times will be discussed.

Antecedent streams are an advantage and a disadvantage. Their courses have been established in a previous erosion cycle, and in the present cycle they maintain themselves by downcutting despite uplift across their channels. They flow from an area of low relief into a canyon which traverses an uplifted belt and emerge upon another area of low relief. In case uplift occurs more rapidly than the stream can erode, ponding results. Overflow from a lake formed in this way may take place along the former channel or by some other course. Examples of antecedent segments in the courses of streams in the Los Angeles region are: Los Angeles River between Dominguez Hill and Los Cerritos, Coyote Creek between Santa Fe Springs and West Coyote Hills, and Ballona Creek between Baldwin Hills and the Palms. A stream with a very small drainage area has maintained itself until recent times across the anticlinal upwarp between Los Cerritos and Signal Hill, and not far from the structural dome of the Signal Hill field. Even though most of the antecedent segments in streams on the coastal belt are indicative of anticlinal structures this relationship is not a necessary one, because the uplifted area may be (1) a fault block with the scarp downstream, (2) a fault block with the scarp upstream, (3) a horst, (4) an upwarp composed of variously deformed strata, or (5) an anticline. The correct solution among these alternatives generally may be determined by a

physiographic or geologic examination. The close association of oil fields and antecedent stream courses is warrant for the investigation of the latter whenever encountered.

Antecedent streams, however, may be a disadvantage. They destroy parts of anticlinally upwarped land surfaces. Ballona Creek has cut away a very significant part of Baldwin Hills. The work of this creek seems to be greater than its volume could accomplish. The form of the alluvial fan of Los Angeles River shows that during some of its history it must have flowed westward into Ballona Creek. If it had not been for the width of the antecedent valley between Baldwin Hills and the Palms, the solution of the structure of Baldwin Hills would have been simpler; and the drilling of wells on the fragment of the uplift near the Palms would have been avoided. In this case the problem is simplified, because the land surfaces and the topographic unconformities are easily determined.

Again we find, as at Seal Beach and also between Bolsa Chica and Huntington Beach, that antecedent streams have cut away so much of the uplift that the structural interpretation on the basis of the physiography is made difficult or impossible.

A more difficult area to interpret occurs where the land has been but slightly uplifted and small antecedent streams have cut broad valleys. This condition occurs near Newport. A part of the uplift isolated by this process may be considered as a separate upwarp.

Piracy is an erosional process by which one stream undermines another and captures its headwaters. The pirate has some competitive advantage over the captured stream, such as the opportunity of developing its valley in softer rocks, a shorter course to the sea, or its flowing into a trunk stream with a low gradient. In the Los Angeles region the stream which drains an area of depression has an advantage over those which traverse one of elevation. A stream may flow out of an alluvium-filled trough into a canyon which traverses an area subject to uplift, and flow out again into a depressed area. Such a stream is antecedent. The uplift across its course hinders its approach to its ultimate grade. A less hampered stream flowing on the alluvial area upstream from the canyon may easily capture its headwaters. This capture may be effected by undermining on the part of the pirate, ponding and overflow, or swinging from side to side on an alluvial fan on the part of the captured streams. Such was the history of the stream which formed Cahuenga Pass. The pass which remains is an air gap. Piracy should always be investigated, because it may lead to proof of an uplift.

Consequent streams are those whose courses are directed by the slope of a recently formed, exposed, or tilted land surface. Before the Dominguez surface was warped, floodwaters doubtless accumulated on it as they do today on the alluvial flats on the coastal belt. The initial tilting of the land directs the flow of the floodwaters, and consequent courses become established. These consequent courses are maintained by downcutting despite the variations in subsequent warping of the land. The consequent stream pattern has very significant re-

lationships to underlying structure. This subject will be considered in a separate paper.

Valley-fill and alluvial fans may cover anticlinal structures. Many wells have been drilled in the hope of finding concealed oil structures. If I may intrude a personal opinion which has been confirmed so far but is not susceptible of proof, I feel that the deformation of the Los Angeles coastal belt is so recent that the alluvial surface would still retain evidence of warping. Alluvial fans may be deceptive in another way. They have broad, gently rounded surfaces which simulate anticlinal warping. This condition becomes difficult to interpret when the canyon from which the sediments are derived is concealed from view. Still more deceptive is the locality in which an alluvial fan has been built and later has been dissected by its stream. The fragments of the fan may be mistaken for those of an anticlinal upwarp.

Hills that are partially covered by alluvium may look like anticlinally warped land surfaces. When a region of moderate relief is depressed until the valleys and most of the ridges are submerged beneath alluvium, the exposed hilltops must be studied adequately before deep drilling is undertaken. Shallow test-hole drilling is advisable if other geologic evidence is not available. In a region of recent deformation the structure of the hill may be anticlinal. It may be, however, part of a fault block. If the anticlines in the vicinity have been truncated by erosion, partially submerged hills may represent the outcrop of harder strata.

When streams overflow their banks, the floodwaters slow down as they pass from the deep channel to the shallow water on the floodplain. Where the rate of speed reduction is greatest, a deposit of sediment is made, and, as a result, low banks are formed on each side of the stream. These banks are called natural levees. They are easily recognized while the stream is flowing in its channel, but should the channel be abandoned, and especially should portions of the natural levees be eroded away, their differentiation from anticlinally warped land surfaces becomes more difficult. Fortunately in the Los Angeles region the major streams flow across the axes of folding, and so the natural levees form an easily recognized angle with the lines of deformation.

Sand dunes are topographic highs that are easily recognized. The sand, itself, the cross-bedding, the gentle windward and the steep leeward slopes, should be sufficient to establish the identity of sand dunes. When the sand dune becomes covered with plants, the drifting of sand along the ground is greatly reduced; and, where the wind becomes quiet behind the sand dunes, the wind-borne sand settles among the plants. As a result such sand dunes become rounded hills. Where sand dunes are grouped together, they surround, more or less completely, areas of slight deposition. The irregularity of the hills and the undrained depressions are sufficient, even on a topographic map, for the recognition of their aeolian character. Sand dunes may cover anticlinally warped land surfaces. The Torrance Field is an example. Test-hole drilling and the correlation of strata offer the best solution. An even more tantalizing possibility occurs in a locality where fine dust drifts over

the sand dunes and is deposited on a plain beyond. More will settle near the dunes than farther away, and the building up of the plain will produce a land form that simulates a tilted surface. This surface may easily be mistaken for the flank of an anticlinally warped surface whose axis is covered by the sand dunes.

In a region of active deformation, if vertical movement has occurred on a fault plane since the close of the last erosion cycle, the fault line will be represented in the topography by a scarp. If no movement has taken place on the fault plane, or if the motion has been horizontal and parallel to the fault plane, there will not be a scarp, unless the rocks on one side of the fault are markedly more resistant to erosion than those on the other side. In this case there would be an erosional scarp which is called a fault-line scarp. Horizontal motion parallel to the fault plane occurs frequently in California. This type of faulting does not make a scarp, unless the topography traversed is very steep. Where, however, the rock sequence on one side of the fault is different from that on the other side, the types of deformation on opposite sides of the fault will be sufficiently different to make possible the detection of the fault in the topography. The topographic effect of thrusting depends on the dip of the fault surface and the resistance to erosion offered by the hanging wall. Many streams follow fault lines. This condition may arise from two causes: either the deformation of the land compels a consequent stream to follow the fault line, or else a subsequent stream develops by headward erosion along the softer brecciated rock of the fault zone. It is possible that the fault zone at the base of the Santa Monica Mountains represents a more continuous fault in the harder rocks at depth. J. E. Eaton,[1] and R. N. Ferguson and C. G. Willis[2] have suggested that the folds along the line of uplift between Newport and Beverly Hills are the surface expression in unconsolidated sediments of a fault zone in deeper rocks.

On the whole, it may be said that the use of the anticlinally warped land surface has led to the rapid development of the oil industry in the Los Angeles coastal belt. However, in forcing physiographic evidence to its extreme application in the later exploration of the region there are many pitfalls.

[1] J. E. Eaton, "Structure of Los Angeles Basin and Environs," *Oil Age*, December, 1923, and January, 1924.

[2] R. N. Ferguson and C. G. Willis, "Dynamics of Oil-Field Structure in Southern California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 5 (September-October, 1924).

GEOLOGICAL NOTES

OIL POSSIBILITIES OF AN AREA NORTHEAST OF PETALUMA, SONOMA COUNTY, CALIFORNIA

As a result of the discovery of small quantities of oil by a well drilled about 5 miles northeast of Petaluma, Sonoma County, California, a geological reconnaissance of the area was recently made by H. W. Hoots, of the U. S. Geological Survey, Department of the Interior, to collect such facts as were readily obtainable regarding the oil possibilities of the area.

These investigations indicated that a block of Pliocene deposits lying northeast of the valley of Petaluma Creek is separated by faults on the southwest and northeast from much older and partically metamorphosed rocks of the Franciscan formation. In this block a pronounced anticline extends from the vicinity of the Eureka school northwestward past the well now being drilled by the Shell Oil Company. Northwest of the Adobe Fort the anticline appears to terminate against a north-south fault, west of which another fold of similar character begins near the north margin of the valley and extends northwestward toward Lynch Creek.

The first well to test the anticline in the Pliocene rocks was drilled in 1923, about 5 miles east-northeast of Petaluma and 1½ miles east of the Bliss school, and is said to have encountered gas. The casing, however, collapsed and a second well was drilled a few hundred feet farther southeast, which yields a few barrels of oil from a depth of about 1,000 feet. More recently the Shell Company began a well about half a mile northwest of the earlier tests, which likewise encountered small quantities of oil in the Pliocene beds and has been drilled deeper to test the underlying Miocene rocks, having reached a reported depth of 3,600 feet late in December, 1926.

All three of these tests were favorably located with reference to structure and will afford highly significant evidence as to the oil possibilities of the area, although several more wells would be required to give conclusive evidence as to the real extent and productivity of the area northeast of Petaluma.

W. C. Mendenhall

U. S. Geological Survey, Washington, D.C.
February 10, 1927

PLANE-TABLE SURVEY UNDERGROUND

A. H. Bell and Joe Markley, during the course of oil investigations for the Illinois Geological Survey in the vicinity of Centralia, Illinois, found it necessary to run levels in a coal mine in order to complete their data for structural studies of the region. This is believed to be one of the first times that a party of geologists

engaged in petroleum work has undertaken a plane-table survey of a coal mine underground. In view of the large area of the mine surveyed, valuable information was contributed to the investigation.

The chief difficulty in underground stadia surveying is that of lighting. In addition to acetylene miner's lamps, both instrument man and rodman carried focusing flashlights. The maximum length of rod that could be used was limited by the height of the entries, which in most places was from 5 to 6 feet. Two rods were carried, one 5 feet and the other 3 feet in length; the two pieces were held together by elastic bands made from old inner tubes. In this way any length of rod from 3 feet to 8 feet could be obtained as needed. The rod was lighted by placing the acetylene lamp on the ground in front and slightly to the side of the rod, facing it, while the rays from the flashlight were directed diagonally downward from a position in front of the top of the rod. In case the instrument man wished any particular part of the rod well lighted, he signaled the number of the foot mark in Morse code.

It was found that the cross-hairs could be well lighted by placing the acetylene lamp on the table in front and to the side of the instrument, and facing so that some of the weaker rays from it shone into the objective lens.

Since in most of the entires there were electric power lines, it was found impracticable to use the compass for orientation. However, an accurate base map surveyed by transit was available, and as in general the entries in this mine are fairly straight and cross each other at most places at right angles, little difficulty was experienced in getting an approximate orientation at instrument stations.

The rate of work was found to be considerably slower than for an equivalent amount of traverse on the surface for the following reasons: (1) difficulty of getting rod well lighted, (2) small average length of shots, about 250 feet, (3) the fact that in all cases where the level of the ground at the instrument was above that at the rod, an angle had to be read. A total of 27,200 feet of traverse (or 5.15 miles) was run in 3 days of 8 hours each, with a total of 117 shots or an average of 13 minutes per shot.

GAIL F. MOULTON

STATE GEOLOGICAL SURVEY DIVISION
URBANA, ILLINOIS
March 1, 1927

REVIEWS AND NEW PUBLICATIONS

Supplement to an Introduction to Sedimentary Petrography. By Henry B. Milner. $5 \times 7\frac{1}{2}$ in. Pp.156. London: Thomas Murby & Co., 1926. 9*s.* 6*d.* New York: D. Van Nostrand Co., 1926. $3.50.

This is a supplement to the author's *Introduction to Sedimentary Petrography* published in 1922 and reviewed on pages 194–96 of Volume 7, No. 2, of this *Bulletin* for 1923. It is intended primarily for those possessing the original volume. Ultimately, the publication of a second edition, containing the two parts in one volume, is planned. Every user of the first volume will want this supplement. It illustrates forcibly the very rapid development of this branch of science since the original volume appeared, and the extensive application that has been made of it to problems of oil geology.

The book is divided into four chapters lettered *A* and conforming in their subject matter to the corresponding four chapters of the original book.

Chapter i (*A*) contains additional material on the technique of the treatment and analysis of sediments. Following one of the most conspicuous developments in drilling—especially with the rotary—during recent years, special consideration is given to core samples and in that connection, in chapter iii (*A*) also, to the use of thin sections in correlation. Accumulated experience and the practical demands for the rapid handling of large quantities of material have led the author to outline a routine for the filing and treatment of samples. While in the original book the author gave full credit to micropaleontology as a means of subsurface correlation, in this supplement he goes farther and makes provision, in his routine, for micropaleontological study of the samples (without, of course, discussing micropaleontology itself). The one question the reviewer would raise regarding the routine relates to the heavy liquid separation of the entire material below 30 mesh. The reviewer has always preferred to work on grains sized by sieving to fall between about 0.25 mm. and 0.05 mm. in diameter (bolting cloth of 100 and 200 mesh). There are several advantages to this closer and finer sizing—among them that it is easier to make a clean, even mount from such grains; but above all, that it is much easier to identify the grains by their bi-refringence. As the heavier minerals tend to accumulate in the finer sizes, none are likely to be missed in this way, and, as a check, the other-size portions can subsequently be rapidly inspected. However, in view of the author's wide experience, one must assume that he has his reasons for not working in this way.

In addition to the routine, various special problems such as the elimination of oil from impregnated samples; the separation of detrital inorganic minerals from coal, oil shales, etc.; mounting coarse grains; and the preparation of thin sections from friable material, are briefly discussed. A valuable paper by Ross on the last-named subject is not referred to in the text though listed in the bibliography at the end of the volume.

Though the author adheres to Canada balsam mounts of entire "crops" of minerals as the basis of his work (and here, also, in view of his wide experience, his practice must be considered significant), yet he gives fuller consideration than in the original volume to the use of index-of-refraction liquids in determining individual grains. Personally, hav-

ing always dodged the determination of most nondescript aggregates and opaque grains under the petrographic microscope, the reviewer was very grateful to the author for the six pages he devotes to them; and no doubt many other petrographers will find themselves in the same situation. There is no real excuse for neglecting such grains except the difficulty involved and the time that may be consumed in their investigation, for in many cases they may be of special significance. The use of colored glasses recommended by the author as an aid in their determination seems helpful. In this chapter the reviewer also learned, for the first time, of a binocular, mon-objective petrographic microscope. Since such instruments are not generally known in this country, it would be of interest to learn who makes them.

Chapter ii (*A*) contains descriptions of the properties of twenty minerals, most of which were not described in chapter ii of the original volume. The features described and the arrangement of the descriptions are the same as in the original volume, except for the addition of a paragraph giving localities and formations in which the minerals have been found.

Chapter iii (*A*) gives a series of definite examples, taken from practice, of the application of the principles of correlation by petrographic methods so interestingly analyzed and presented in chapter iii of the original volume. For the beginner it is doubtless helpful to see just what criteria others have used in special cases, and how much or little they have been able to accomplish with the methods presented by these two books. But, as the author himself indicates, each problem has its own special features, and direct observation, experience, and good judgment are essential for the best solution. Such value as the text of this chapter may have is not, however, in the reviewer's opinion, enhanced by the accompanying illustrations (Figs. 66–83) of the mineral crops discussed. These might well be omitted and the price of the book correspondingly reduced.

The most original contribution made in this supplement is undoubtedly chapter iv (*A*) in which "The significance of detrital and authigenic minerals in the natural history of sedimentary rocks" is discussed. Here the minerals described in chapters ii and ii (*A*) are taken up one by one, and available data regarding the evidence they give about the environments through which they have passed are brought together. Though the data on this subject scattered through the literature are meager and inadequate, and in large part unreliable because based on insufficient evidence, the author has done a great service in initiating this systematic treatment of the subject and focusing attention on what is, more or less consciously, the basis and ultimate goal of all work in sedimentary petrology. It is regrettable, however, that, recognizing such a variety of distinct environments as arid, subaereal, fresh-water, ground-water, marine, acid, and alkaline waters (see, for example, "barytes," p. 105), the author should counteract that very differentiation which he makes and which he is trying to make the reader realize, by having, in the summary table on page 103, a column headed merely "Stab." (Stability). It is just on the fact that most minerals are not equally stable under the great variety of possible environments, that the point of view here presented is based; and in no way could this have been better driven home than by having, under the heading "Stab.," subheadings for each of the different environments recognized. "Stability," unrestricted, on the contrary is made meaningless by the author's own treatment and can only be a substitute for some concept like "ratio of frequency in sedimentary rocks to frequency in igneous rocks."

A minor criticism relates to the treatment of clay minerals. The author is probably quite right in saying under "Kaolinite" (pp. 111–12), that that mineral is "often totally

absent from argillaceous rocks"; it is a pity, however, that at the same time he does not refer to such work as that of Larsen, Ross, Shannon, and Wherry on the clay minerals.

Appendix I contains tables to help in running down the minerals encountered in sedimentary rocks.

A very happy thought is the presentation in Appendix II of a list of eight minerals that may be expected, but have not yet been found, in sedimentary rocks. This will implant in the back of the mind of many a worker in this field the pleasant hope that some day he may come across one of these lost sheep, and thus adds to the zest of the work at the same time that it helps perfect the record.

Finally, Appendix III supplies a bibliography from 1922 to date, supplementing the bibliography in the original volume.

Marcus I. Goldman

U. S. Geological Survey, Washington, D.C.
March 2, 1927

The Geology of Oil, Oil-Shale, and Coal. By Murray Stuart. Mining Publications (London, 1926). 104 pp. Price, 7*s*. 6*d*.

"This little treatise is an attempt to furnish a connected outline of the origin and mode of accumulation of oil deposits, oil shales, and seams of ordinary household, or, as it is sometimes called, bituminous coal." The origin of coal, as stated by Professor Lapworth in lectures delivered in 1906, is accepted and the origin of oil as interpreted from field studies in Burma and published in Vol. 12 of the *Journal of the Institution of Petroleum Technologists* is reiterated. Unfamiliarity with coal deposits and oil fields in other portions of the world leads the writer to present and defend a hypothesis which cannot meet with general acceptance, while there is almost no discussion of the relative merit of the most widely accepted hypotheses.

Mr. Stuart contends that coal accumulated in sedimentary basins collaterally with oil, the coal being deposited nearer the land than the oil and oil shales between them. He is impressed with the new processes of Dr. Friedrich Bergius and Dr. Franz Fisher for generating oil from coal. As presented at the international conference on bituminous coal held at Pittsburgh, Pennsylvania, November 15, 1926, the Bergius process is a hydrogenation of coal at high pressure and temperature which will yield about three barrels of oil from one ton of coal, and the Fischer process is the synthesis of hydrocarbons from carbon monoxide and hydrogen at atmospheric pressure and relatively low temperature with the aid of a catalyst (either cobalt or iron), which will yield about one barrel of oil from one ton of coal. Artificial generation of one hydrocarbon from another does not, however, prove a common origin.

In the first three chapters a picture of the origin and deposition of oil, oil shale, and coal is given; all are derived from the carbonization by bacterial action of vegetable matter (largely spores) in fresh-water lagoons and swamps and are transported at a later time into brackish or salt-water deposits as actual oil, resinous spores (the oil shales), and carbonaceous mud (coal). The normal sequence of sedimentary deposition from the shore outward would be conglomerate, sandstone, ordinary clay, oil-bearing clay, and carbonaceous mud; or else, conglomerate, sandstone, and sediments, which would form oil shales, cannel coal or torbanite, and coal. The character of the coal (and of the oil also), whether lignite, bituminous, etc., would be determined by the original vegetable material

and bacterial action, and "having been laid down as a sediment in brackish or salt water, a lignite would remain a lignite all the days of its existence."

To dismiss with a paragraph the evidence that at least some coal has an autochthonous origin and to postulate decomposition and a double transportation of material—to the lagoon and later to the semi-marine deposits—in the face of all that has been revealed by geological investigation and by the microscope concerning the composition of coal are unwarranted presumptions. To account for the enormous amount of coal and oil known to exist in the world by a single instead of a dual transportation of material is sufficiently difficult. Also, oil is found associated with marine faunas and microfaunas, and coal, with land floras: different conditions of sedimentation from those pictured by Mr. Stuart. Oil of the same physical and chemical composition seems to be indigenous to formations ranging in age from the Cambrian to the Pliocene, but coal is infrequent in pre-Carboniferous strata and, considered throughout the world in the geological time scale, grades from anthracite and bituminous coal in the Paleozoic to peat in the Quaternary.

Oil is supposed by Mr. Stuart to have been formed in the lagoons or swamps from leaves and wood of plants containing wood-oil and resin. The origin of oil in Lower Paleozoic rocks which were deposited before the higher types of plants were evolved is not stated; nor is the microscopic composition of known source-rocks mentioned; nor are modern occurrences of oil in swamps mentioned. Mr. Stuart holds that oil is liberated in minute globules and held under water by decaying vegetation. "When such a swamp or lagoon became breached and its contents carried out to sea by rivers, the oil would be deposited by the ordinary mud." Thus the deposition of oil as oil is postulated and is supported by experiments proving that when oil, water, and powdered shale are shaken up together the oil adheres to the shale!

Metamorphism is held to have no connection with oil and coal. The reviewer believes that the few known exceptions to the carbon-ratio hypothesis of David White's to account for the relationship of gas to oil do not condemn it, but appeal to the adage "exceptions prove the rule." To deny the progressive change in the composition of coal in geological time is comparable to denying the local metamorphism of coal beds near igneous intrusions.

Chapter iv is an ingenious explanation for the origin of oil in certain marine dolomitic limestones without accounting for its concentration. Not all oil-bearing limestones are, however, dolomitic; the El Abra (so-called "Tamasopo") limestone of the "South" fields of Mexico is reported not to be dolomitic. Mr. Stuart states that oil is derived from microscopic surface life only when it falls to the bottom, where there are sulphur-making bacteria. The bacteria produce petroleum from the dead protoplasm slowly, and by the time globules of oil are formed they are covered by more recent deposits and are sealed in place by the precipitation of calcium carbonate. Under such bottom conditions more or less sulphide of iron may be deposited, especially in salt beds, and may alter limestone into gypsum by hydrochemical metamorphism. This accounts for the occasional association of oil and gypsum.

Chapter v describes the formation of oil in detrital sedimentary rocks in the sea (after the superfluous lagoon-swamp fresh-water stage), and the picture presented seems to the reviewer to have world-wide application. Sulphur-making bacteria are confined to the stagnant portions of the sea and cause the deposition of sulphide of iron, which, in turn, accounts for the bluish color of detrital marine sediments. (Oil is almost invariably associated with "blue" rather than "red" shales.) Oil is derived from Foraminifera in

shale. Similarly, the oil globules (from the swamps) are attacked by these bacteria and the resulting oil is ultimately squeezed into overlying sand by the weight of overlying accumulating sediments. Slight changes in salinity of water or in the composition of the Foraminifera or oil globules would affect the action of the bacteria and cause the generation of different grades of oil in different sands in the same field. Also, the temporary destruction of the bacteria would account for a salt-water sand between prolific oil sands (a good example is the Layton sand in the Tonkawa field, Oklahoma, which carries salt water in contrast to overlying and underlying oil sands). No mention is made of natural gas. Must one imagine bubbles of gas carried into the sediments because the composition of oil does not change after formation?

Chapter vi and the following chapter draw upon the geological history of Burma to furnish data relevant to oil formation. The statement appears that in silicification of wood the carbonaceous matter may be converted into oil. Connection between silicification and oil accumulation has yet to be proved, though many oil shales, as in Colorado and California, are siliceous.

In chapter vii an attempt is made to show that oil has been derived "from coal or lignite having a suitable carbon ratio" in certain fields of Burma and India by overthrust faulting and dynamo-metamorphism. Comparable occurrences of oil and gas could probably be found elsewhere in the world where there are no coal beds.

The concluding chapter contains a list of guides to the search for oil deposits which differ markedly from the standard of seepages, structure, and reservoir rocks. A brief statement about the oil possibilities in Great Britain, Burma, Northwest India, New South Wales, and Queensland is followed by a speculation on the history of life on the earth and its environmental conditions.

Two thoughts present themselves to the reviewer: first, the important rôle that bacteria have played and do play in all geological processes, whether or not their part in the formation of coal and of oil is exaggerated in the treatise under discussion; and second, the state of general knowledge regarding the origin of coal and oil which permits the incubation of such an ingenious hypothesis, iconoclastic, yet stimulating to the research concerning the origin and investigation of oil now being conducted under the auspices of the National Research Council at Washington. Part of the story, such as the action of sulphur-bearing bacteria and the importance of changes in the salinity of the water, is highly commendable; but the transportation of oil as oil is difficult to believe, and the original sedimentary sequence from coal to oil shale and oil is at variance with geological observations in many different regions.

SIDNEY POWERS

NEW PUBLICATIONS

"Technical Paper 370," by C. P. Bowie. U. S. Bureau of Mines, Department of Commerce, Washington, D.C.

"This report gives results of extensive experiments with the Bowie-Gavin apparatus in cracking tars and heavy oils which, being perhaps the most accessible, will first be utilized to supplement the production from wells. This process can be used to recover oil from oil shale and oil-soaked sands and, when the necessary economies in its operation are worked out, the process can be applied to cracking asphalts, still bottoms, and similar heavy residuals at refineries." Free distribution.

"Petroleum in 1924," by G. B. Richardson and A. B. Coons. U. S. Bureau of Mines, Department of Commerce, Washington, D.C., 1926. 74 pp.; 4 figs. Price, $0.15.

CANADA

"Bituminous Sands of Northern Alberta: Occurrence and Economic Possibilities," by S. C. Ells. *Report 632, Mines Branch, Department of Mines,* Ottawa, Canada. 244 pp.; 12 maps and sections. Price, $0.75.

FLORIDA

"A Review of the Structure and Stratigraphy of Florida, with Special Reference to the Petroleum Possibilities," by Stuart Mossom. *17th Ann. Rept. Florida State Geological Survey,* by Herman Gunter. Tallahassee, Florida, 1926, pp. 169–275.

GENERAL

Stories in Stone (a popular book), by Willis T. Lee. New York: Library of Modern Science, D. Van Ostrand & Company, 1927. 226 pp. Price, $3.00.

Small Geological Map of Europe, prepared by F. Beyschlag and W. Schriel. Preussischen Geologischen Landesanstalt, Berlin, 1925. Printed by Gebrüder Borntraeger, Berlin, W. 35. Major formations shown in colors. Scale, 1:10,000,000. Also a *Tectonic Map of Europe* showing old land areas and tectonic zones, printed in black on transparent paper as a top sheet for the colored map.

THE ASSOCIATION ROUND TABLE

RESEARCH ANNOUNCEMENT

Arrangements have been made with Mr. C. M. Nevin, of the geological faculty of Cornell University, to conduct a series of experiments on the movement of oil and water through sands, to determine, if possible, the relation of permeability of oil sands to problems of migration and recovery. A portion of the expense of the necessary laboratory equipment has been pledged from the Research Fund of the Association.

The successful prosecution of this research depends largely upon being able to secure a large number of cores (of any diameter) or chunk samples from both productive and non-productive sands. An abundance of material is needed. The work is being undertaken on the assumption that members of the Association will assist in securing such samples and forwarding them direct to Mr. Nevin, or at least notifying him where they may be obtained.

Will any member who reads this notice kindly comply with this request without further solicitation, addressing C. M. Nevin, Geological Department, Cornell University, Ithaca, New York ?

W. E. Wrather
Chairman, Research Committee

THE OKLAHOMA GEOLOGICAL MAP

A statement regarding the disbursement of funds raised for the colored areal geological map of Oklahoma which was published January 19, 1927, by the U. S. Geological Survey, was made in Volume 9 (1925), p. 920. That statement showed $3,396.25 raised from subscriptions and a balance of $144.37 remaining . On February 28, 1927, this balance with accrued interest, amounting to $155.60 in all, was sent to the National Research Council to be expended for further areal mapping in Oklahoma by the U. S. Geological Survey under the direction of H. D. Miser. The map is sold by the Survey for $1.50 and no free copies are available to the original subscribers to the fund.

Sidney Powers, *Treasurer*

Tulsa, Oklahoma
March 4, 1927

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualifications of these applicants, please send it promptly to J. P. D. Hull, Business Manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each applicant.)

FOR FULL MEMBERSHIP

James Walton Hunter, Tampico, Mexico
Carroll H. Wegemann, Ellis A. Hall, Shirley L. Mason
Lew Suverkrop, Taft, Calif.
E. Huguenin, Walter A. English, W. W. Copp

FOR ASSOCIATE MEMBERSHIP

Joe Lawton, Pawhuska, Okla.
Stuart K. Clark, C. L. Arnett, Glenn C. Clark
Joe Bernard Lovejoy, Wichita Falls, Tex.
H. B. Fuqua, C. E. Yager, David Donoghue
James Paul McKee, Ardmore, Okla.
Samuel H. Woods, A. W. Lauer, John N. Troxell
Raymond F. McMillen, Tulsa, Okla.
A. F. Truex, A. W. Duston, Thos. W. Leach
Coe Stanley Mills, Fort Worth, Tex.
Ray V. Hennen, R. J. Metcalf, A. M. Hagan
Walter L. Moreman, Fort Worth, Tex.
W. M. Winton, Gayle Scott, F. B. Plummer
Clarence Whitney Sanders, Tulsa, Okla.
T. K. Harnsberger, W. H. Emmons, John Lind, Jr.
Elgean Shield, Coleman, Tex.
W. L. Goldston, Jr., Charles O. Doub, Leon F. Russ
Clyde L. Wagner, Tulsa, Okla.
V. Elvert Monnett, G. E. Anderson, Sylvan H. Andrews
Verde W. Watson, Amarillo, Tex.
W. C. Toepelman, Junius Henderson, J. V. Howell

FOR TRANSFER TO FULL MEMBERSHIP

James Bryan Dorr, Tampico, Mexico
Walt M. Small, E. L. Estabrook, Ellis A. Hall
Ira Edward Dugan, Ponca City, Okla.
Glenn C. Clark, Stuart K. Clark, W. A. J. M. van der Gracht
Robert McNeely, Ponca City, Okla.
C. L. Arnett, Glenn C. Clark, Stuart K. Clark
Harry W. Oborne, Denver, Colo.
E. Russell Lloyd, Ross L. Heaton, L. C. Snider
Ernest S. Pratt, Ponca City, Okla.
Glenn C. Clark, Stuart K. Clark, Edward L. Jones, Jr.

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

WITHERS CLAY is geologist for Woodley Petroleum Company, of Shreveport, Louisiana. Mr. Clay has been doing subsurface work in the district of Brownwood, Texas.

J. VOLNEY LEWIS, of Rutgers College, New Brunswick, New Jersey, was working in Porto Rico last March. His present address is care of The Gulf Companies, 21 State Street, New York, N.Y.

MR. and MRS. A. E. CHEYNEY, Box 150, Emporia, Kansas, announce the birth of Daryl Dee, February 28, 1927.

The 2,000-acre block on which the Barnsdall Oil Company recently completed a 300-barrel discovery well in western Butler County, Kansas, was taken on the geological recommendation of DAVID P. DEAN and J. DAVID HEDLEY. Mr. Dean is now in charge of the Barnsdall geological staff in Texas, located at Cisco, and Mr. Hedley is district geologist for the Barnsdall at Amarillo.

GAIL F. MOULTON recently made a trip to the Hiawatha Dome well in Moffatt County, Colorado, in the interest of W. T. Morris, of New York. He also has been in the Baker, Montana, gas field for Chicago interests who are undertaking further prospecting in the area.

CHARLES A. MILNER, JR., is working in Texas for the Derby Oil and Refining Corporation. His address is Box 686, Cisco, Texas.

The ILLINOIS GEOLOGICAL SURVEY was represented at the meeting of the American Institute of Mining and Metallurgical Engineers in New York by GAIL F. MOULTON, who gave a paper summarizing the developments in the Mississippi Valley fields for 1926.

E. DEGOLYER was elected president and director, GEORGE OTIS SMITH, vice-president and director, and F. JULIUS FOHS, vice-president and director of the American Institute of Mining and Metallurgical Engineers at the annual meeting held in New York, February 14–17.

C. A. MIX is with The California Company, Room 8, Webster Building, Amarillo, Texas.

HENRY L. HUMMEL, chief geologist of the White Eagle Oil and Refining Company, has moved from Wichita, Kansas, to Fort Worth, Texas.

M. E. STILES and R. T. THOMAS, of the Pure Oil Company, have moved from Mexia to the New Petroleum Building, Fort Worth, Texas.

MISS H. T. KNIKER is now with the Phillips Petroleum Company, San Angelo, Texas.

THEODORE A. LINK, of the Imperial Oil Company, returns to Colombia in June after spending a year at the University of Chicago in experimental work on folding and faulting by means of plastic models.

RICHARD T. BRIGHT is in charge of the office of the U. S. Geological Survey at Shawnee, Oklahoma.

CHARLES DOOLITTLE WALCOTT, secretary of the Smithsonian Institution, died February 9 at the age of sixty-nine. His first interest in geology arose when the wheels of the

farm wagon which he drove as a boy turned up fossils in the road. He organized the Carnegie Institution in 1902 and had been secretary of the Smithsonian Institution since 1907.

W. B. Heroy, vice-president of the Sinclair Exploration Company, of New York City, spent February and March in Venezuela.

Sidney Paige, of the Esperanza Oil Corporation, of New York, visited the Mid-Continent fields in February.

Sylvan S. Price, vice-president of the Dixie Oil Company, made his annual inspection trip to Venezuela in February.

Oliver B. Hopkins, chief geologist of the Imperial Oil Company, of Toronto, spent February and March in Colombia and Peru.

Ralph Richards, of the Standard Oil Company of New Jersey, has been transferred from Argentina to Venezuela. He visited in Washington in March.

George Kroenlin, of the Gilliland Oil Company, is living in Sheffield, Texas.

W. van Holst Pellekaan, of the Roxana Petroleum Corporation, returned to Dallas in March from a trip to Europe.

A. Faison Dixon, of New York, visited Tulsa in February.

C. C. Toomey is geologist for C. J. Wrightsman of Tulsa.

W. T. Sherry is in charge of the land department for C. J. Wrightsman.

Frank Buttram spent February in California.

Marvin Lee, of Wichita, Kansas, is consulting geologist for the K.C., M., & O. Railway.

George Steiner has been making an extensive torsion-balance survey in the vicinity of New Orleans, Louisiana. Mr. Steiner's new office location is in the Post-Dispatch Building, Houston, Texas.

C. J. Wohlford is in charge of the land department of the Amerada Petroleum Corporation at San Angelo, Texas.

Albert D. Brokaw, of the firm of Brokaw, Dixon, Garner, & McKee, 120 Broadway, New York City, recently visited the Mid-Continent field.

H. J. Owen has resigned his position with the Ohio Oil Company and is now with the Marland at Wichita Falls.

Miss Alva C. Ellisor, paleontologist for the Humble Oil and Refining Company, recently spent a few weeks in Shreveport, Louisiana.

C. M. Bennett, vice-president of the Louisiana Oil Refining Corporation, of Shreveport, has been on a business trip to Barbados.

I. M. Hawkins has left the employ of the Louisiana Oil Refining Corporation to go to Venezuela.

George Morgan, of the Dixie Oil Company, was in Shreveport February 14.

Roger Dennison, from the Tulsa office of the Amerada Petroleum Corporation, recently spent a few weeks in Shreveport.

L. P. Garrett, of the Gulf Production Company, was on a business trip in the Louisiana-Arkansas territory in February.

Dr. I. Maizlaish, professor of physics at Centenary College, addressed the Shreveport Geological Society at the weekly luncheon, February 21, on the question of founding a Louisiana Academy of Sciences.

The Palmer Corporation has a 20,000,000-cubic-foot gas well in Sec. 33, T. 17 N., R. 6 E., Richland Parish, Louisiana, which is producing from a sand below the red shales at 2,432 feet.

The SHREVEPORT GEOLOGICAL SOCIETY has appointed a committee to decide upon the applicability of the new Upper Cretaceous section of south Arkansas, recently published by CARL H. DANE, for the subsurface formations of south Arkansas and Louisiana. A function of this committee will be the consideration of any necessary re-correlations of the various producing sands in the Shreveport area.

ED W. OWEN, geologist for John C. Keys, of Oklahoma City, is stationed at Abilene, Texas.

MAX MORGAN, chief geologist of the Wentz Oil Company, is spending considerable time in western Texas.

G. C. POTTER resigned from the Tidal Oil Company March 15 to become chief geologist for the McMan Oil and Gas Company, Drew Building, Tulsa.

A. E. FATH is temporarily located in Tulsa.

MARION H. FUNK resigned his position as geologist with the Louisiana Oil Refining Corporation, of Shreveport, to become chief geologist for Trinidad Oil Fields, Inc., Port of Spain, Trinidad, B.W.I.

E. JABLONSKI, of the Vacuum Oil Company, has been transferred from Poland to Eastland, Texas.

W. A. PRICE, consulting geologist of Houston, has moved to the Neils Esperson Building.

IRVING PERRINE, W. C. KITE, and DEAN STACY, of Oklahoma City, are frequent visitors in Tulsa and guests at the Tulsa Geological Society luncheons.

SIDNEY POWERS made a swing through the south Mid-Continent and the Gulf Coast in February.

GEORGE C. MATSON, consulting geologist at Tulsa, has moved his offices from 408 Cosden Building to 638 Kennedy Building.

L. G. WEEKS is now in South America. His address is Standard Oil Company, Edificio Banco Boston, Avenida Roque Sanz Pena 567, Buenos Aires, Argentina.

MR. and MRS. SIDNEY EARL MIX announce the birth of their third child, a son, Hugh Coffland Mix, February 12, 1927, Shreveport, Louisiana. Mr. Mix is chief geologist for the Gulf Company at Shreveport.

F. W. PENNY, of the Phoenix Oil and Transport Company of London, visited the Mid-Continent fields last March. Mr. Penny is stationed in Roumania.

HARRY W. BELL, in charge of salvage and standardization of equipment for the Pure Oil Company, recently made a business tour of the company's properties in Oklahoma, Texas, Louisiana, and Arkansas. Mr. Bell makes Chicago his headquarters.

R. CLARE COFFIN, of the Midwest Refining Company, spent part of March in California.

It is reported that a well drilled in Jackson Parish by the Louisiana Oil Refining Corporation passed from Midway Eocene into Lower Cretaceous formations at a depth of 2,429 feet. No Upper Cretaceous was recorded.

R. V. HENNEN is credited with discovering the new Transcontinental-Mid-Kansas field in Pecos County, Texas, as well as a new field 15 miles west of Santa Barbara, California. In the latter field the discovery well made 450 barrels of oil from a depth of 1,500 feet.

Memorial

HARRY AID

The Association recently lost a valuable and well-loved member through the untimely death of Harry Aid at Fort Worth, Texas.

Harry Aid was born on October 21, 1897, at Gallatin, Missouri. He spent his early youth at Gallatin, graduating from high school there. He subsequently attended Missouri School of Mines at Rolla and Leland Stanford University at Palo Alto, California, specializing in the study of geology. Before completing his studies he enlisted in the Air Service during the latter part of the world-war. He then returned to his studies and graduated from Leland Stanford in 1922. After graduation he was engaged in exploratory geological work for the Gulf Oil Corporation in Mexico and the United States.

On September 4, 1926, he married Miss Marion Baxter at Los Angeles, California. The newly married couple took up their residence at Amarillo, Texas, where Mr. Aid served the Gulf Company in the capacity of district geologist.

He became ill with typhoid fever on December 18, 1926, was transferred to Fort Worth, Texas, for special treatment, and died in that city January 4, 1927, at the age of twenty-nine years.

He was a member of the Grace M.E. Church of Berkeley, California, of the Gallatin Chapter of the Masonic Lodge, of the Kappa Sigma fraternity, of the American Association of Petroleum Geologists, and of the American Association of Mining and Metallurgical Engineers.

He is survived by his wife, Marion, his father and mother, Mr. and Mrs. George Aid, two sisters, Genevieve and Mamie, and two brothers, Kenneth and Herbert.

B. E. Thompson

EDWIN THEODORE DUMBLE

Edwin Theodore Dumble, dean of geology, who retired from active service of the Southern Pacific Company on May 1, 1925, died on the night of January 25, 1927, Nice, France.

Dr. Dumble was born in Madison, Indiana, March 28, 1852, and received a B.S. degree from Washington and Lee University, Virginia. During the early years of his life, Dr. Dumble moved his residence to Houston, Texas. He was state geologist of Texas from 1887 to 1896. About this time the Southern Pacific Company selected him as consulting geologist and manager of all of their oil properties which embraced Texas, California, and Mexico. He was the organizer and successful promoter of the Kern Trading & Oil Company (Associated and Pacific Oil Companies), Rio Bravo Oil Company, and East Coast Oil Company, S.A., all belonging to the Southern Pacific Company.

From the time of his graduation at Washington and Lee, Dr. Dumble was primarily interested in petroleum geology. He was among the first to begin this practice. Due to his ability to apply this science along economic lines, he had a great influence in its spread

and use in other large oil organizations. Dr. Dumble spent twenty-nine years with the Southern Pacific Company. He was the author of many valuable publications bearing on the geology of Texas and Mexico, among the most notable of these being the volumes: *Brown Coal and Lignite* and *Geology of East Texas*. Dr. Dumble also assisted greatly in the introduction of paleontology and the study of Foraminifera into the oil business. He had the first laboratory in Houston devoted to the microscopical examination of well-cuttings, this laboratory devoting most of its time to the study of Tertiary Foraminifera.

Dr. Dumble's scientific achievements brought him many honors. He was a member of the Geological Society of America, American Association for the Advancement of Science, Texas Academy of Science, American Institute of Mining and Metallurgical Engineers, California Academy of Science, and American Association of Petroleum Geologists.

The scientific contributions of Dr. Dumble are of great importance; yet his greatest contribution was the inspiration he gave to members of the profession and to his associates. Dr. Dumble was always patient and instructive with all of his employees and probably considered it a great achievement to turn out men and place them on the road to success equipped with as much of his knowledge as he could impart to them. Among the men now prominent in the oil industry who at some time in their careers were connected with Dr. Dumble might be mentioned the following:

T. R. Batte	James Hutcheson
C. L. Baker	Lee Hager
J. W. Bostick	Joseph Jensen
W. F. Cummins	M. E. Lombardi
N. F. Drake	W. J. Luke
L. P. Garrett	A. C. McLaughlin
E. G. Gaylord	J. M. Sands
G. C. Gester	J. A. Taff
S. H. Gester	

Dr. Dumble had but recently retired to his plantation at Tunstall, Virginia, at which place he intended to give the greater portion of his time to further study and research in geology. Due to the gradual failing of his health, he went to Nice, France, with his family about a month before his death, to recuperate. He was buried in the English cemetery at Nice.

The oil industry and geological profession has lost one of its most staunch supporters and a man who was a friend to anyone with whom he came in contact and who was ready at all times to lend a helping hand to those in trouble and need. Surely his spirit will live on in the men he trained and the service he gave to science.

JOHN R. SUMAN

D. D. FINLEY

D. D. Finley was born in Wellington, Kansas, and received his early education in the schools of that city. He studied engineering from 1912 to 1914 in the University of Kansas, where he became interested in petroleum geology, and attended the Missouri School of Mines in 1915 and 1916, graduating in petroleum geology and engineering in the latter year.

Upon leaving school he became associated with the Gypsy Oil Company as petroleum engineer. In 1918 he became an independent petroleum geologist and engineer, operating in the oil fields of Oklahoma, southern Kansas, and Kentucky. In 1923 Mr. Finley joined the staff of the Internal Revenue Department of the Government in the oil and gas section. In 1924 he affiliated with the firm of Mattison & Davey, in charge of the engineering department of their Tulsa office. After remaining with Mattison & Davey a year, he again branched out as an independent operator and engineer and was instrumental in forming the National Petroleum Engineering Corporation. Affiliated with him in this enterprise were Senator George E. Chamberlain and Peter Q. Nyce, of Washington, D.C., W. N. Thayer, former chief of the oil and gas section of the Internal Revenue Department, Harry A. Campbell and F. Lee Stewart, of Tulsa. Mr. Finley was with this company at the time of his death, which occurred June 23, 1926, as the result of an automobile accident. He is survived by his widow and two children.

Mr. Finley was a member of the American Association of Petroleum Geologists and the Society of American Military Engineers. His pleasing personality and buoyant spirit will be remembered by those with whom he came in contact.

L. E. Kennedy